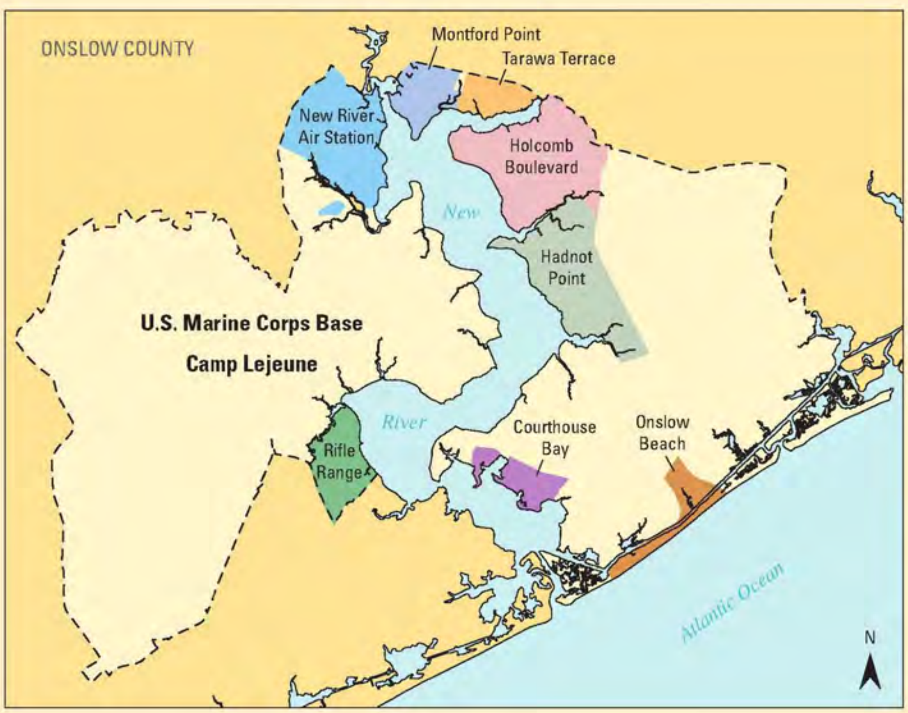
EXHIBIT 27

ATSDR
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

Expert Panel Assessing ATSDR's Methods and Analyses for Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point, Holcomb Boulevard, and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina

April 29–30, 2009



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Cover. Location of U.S. Marine Corps Base Camp Lejeune, North Carolina, and historical water-supply areas.

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Glossary and Abbreviations

Definitions of terms and abbreviations used throughout this report are listed below.

ASCE	American Society of Civil Engineers
AST	above-ground storage tank
ATSDR	Agency for Toxic Substances and Disease Registry
AWWA	American Water Works Association
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAP	community assistance panel
CD-ROM	compact disc, read-only memory
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CI	cast iron
DCE	dichloroethylene
	1,1-DCE 1,1-dichloroethylene or 1,1-dichloroethene
	1,2-DCE 1,2-dichloroethylene or 1,2-dichloroethene
	1,2-*c*DCE *cis*-1,2-dichloroethylene or *cis*-1,2-dichloroethene
	1,2-*t*DCE *trans*-1,2-dichloroethylene or *trans*-1,2-dichloroethene
DHAC	Division of Health Assessment and Consultation, ATSDR
DOD	U.S. Department of Defense
DON	U.S. Department of the Navy
EPANET or EPANET 2	a water-distribution system model developed by the USEPA
ERG	Eastern Research Group, Inc.
ft	foot or feet
Ga. Tech	Georgia Institute of Technology
gal	gallons
gpm	gallons per minute
HPIA	Hadnot Point industrial area
HUF	hydrologic unit flow
IRP	Installation Restoration Program
LGR	local-grid refinement
MESL	Multimedia Environmental Simulations Laboratory, Georgia Institute of Technology
MGD	million gallons per day
μg/L	micrograms per liter
MODFLOW	a three-dimensional groundwater-flow model developed by the U.S. Geological Survey

MODPATH	a particle-tracking model developed by the U.S. Geological Survey that computes three-dimensional pathlines and particle arrival times at pumping wells based on the advective flow output of MODFLOW
MT3DMS	a three-dimensional mass transport, multispecies model developed by C. Zheng and P. Wang on behalf of the U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi
NAVFAC	Naval Facilities Engineering Command
NCEH	National Center for Environmental Health, U.S. Centers for Disease Control and Prevention
NTD	neural tube defect
PCE	tetrachloroethylene, tetrachloroethene; also known as PERC® or PERK®
PEST	a model-independent parameter estimation and uncertainty analysis tool developed by Watermark Numerical Computing
ppb	parts per billion
PVC	polyvinyl chloride
SGA	small for gestational age
Surfer®	a software program used for mapping contaminant plumes in groundwater
TCE	trichloroethylene, 1,1,2-trichloroethene, or 1,1,2-trichloroethylene
TechFlowMP	a three-dimensional multiphase multispecies contaminant fate and transport analysis software for subsurface systems developed at the Multimedia Environmental Simulations Laboratory (MESL), Georgia Institute of Technology
THM	trihalomethane
USEPA	U.S. Environmental Protection Agency
USMC	U.S. Marine Corps
USGS	U.S. Geological Survey
USPHS	U.S. Public Health Service
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
WTP	water treatment plant

Expert Panel Assessing ATSDR's Methods and Analyses for Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point, Holcomb Boulevard, and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina

April 29–30, 2009

Morris L. Maslia, Editor

Executive Summary

On April 29–30, 2009, the Agency for Toxic Substances and Disease Registry (ATSDR) held a 2-day expert panel meeting in Atlanta, Georgia. ATSDR convened the panel to receive input from experts on methods and analyses being proposed by ATSDR for historical reconstruction of groundwater flow, contaminant fate and transport, and distribution of drinking water at Hadnot Point, Holcomb Boulevard, and vicinity, U.S. Marine Corps (USMC) Base Camp Lejeune, North Carolina. As discussed during the meeting, ATSDR is at the early stages of water-modeling activities for these areas of the base. Therefore, the agency is requesting and relying on panel input to comment on and provide suggestions for the agency's continued water-modeling efforts. The purpose of water-modeling activities at Camp Lejeune is to reconstruct estimates of historical contaminant concentrations in drinking-water systems that served the base during the time frame of the current ATSDR health study (1968–1985).[1] Using information derived from water-modeling methods, ATSDR will estimate specific contaminant concentrations in drinking water and quantify potential exposures for people living and working on the base who received water from the Hadnot Point and Holcomb Boulevard drinking-water systems. Prior to and during the 2-day meeting, panel members received information on activities regarding ATSDR's epidemiological study, which is evaluating exposure in utero and up to 1 year of age to volatile organic compound (VOC)-contaminated drinking water at the base during the period 1968–1985 to assess specific birth defects and childhood cancers. Information provided to panel members included the purpose of the historical reconstruction and water-modeling activities in relation to the study, the methods that will be used for data analyses and historical reconstruction, and results obtained to date. Panel members also were provided with results for the Tarawa Terrace base-housing area, which have already been completed, peer reviewed, and published (Maslia et al. 2007, 2009a). During the panel meeting, ATSDR's epidemiological study and water-modeling teams presented detailed information and summaries of the overall goals of the epidemiological study and specific water-modeling activities, respectively, conducted to date for Hadnot Point, Holcomb Boulevard, and vicinity.

[1] The current ATSDR health study is titled, "Exposure to Volatile Organic Compounds in Drinking Water and Specific Birth Defects and Childhood Cancer at U.S. Marine Corps Base Camp Lejeune, North Carolina."

Prior to the meeting, ATSDR provided panel members with a charge that included five overall questions to consider. Specifically, the questions asked panelists to review and offer recommendations regarding five topics associated with ATSDR's water-modeling efforts:

1. overall approach to quantifying historical concentrations;
2. data analysis, modeling complexities, and modeling methods;
3. calibration targets for comparing measured and simulated water-quality data;
4. model to examine the intermittent interconnection between Hadnot Point and Holcomb Boulevard; and
5. project schedule time line.

Throughout the meeting, panelists discussed these questions, provided suggestions and recommendations, and raised issues for ATSDR to consider during its on-going water-modeling activities. The panel concurred that the water-modeling component of ATSDR's current health study was worthwhile and agreed it would be possible for ATSDR to reconstruct potential historical exposures suitable for the epidemiological study. At the conclusion of the second day of the meeting, panelists provided specific recommendations for ATSDR to consider, which are briefly summarized here and detailed in Section 6.0 of this report.

1. Panelists concurred that using physically-based, data-driven models were best for modeling the groundwater and water-distribution systems, and strongly advocated conducting sensitivity and uncertainty analyses (e.g., Monte Carlo simulation) to bound model estimates.

2. Several panel members recommended that ATSDR concentrate more of its efforts on how to get a reliable, realistic model for the time periods when there are no data, rather than expending time and resources on model calibration criterion. Overall, the panelists did not agree with the calibration criterion ATSDR planned to use. The panel suggested ATSDR not pre-specify numerical values of calibration targets. There was consensus among panel members that emphasis should be placed on more objectively estimating model parameters than on trying to closely match observed water-level or concentration data with model-simulated results for model calibration.

3. The panel agreed that the epidemiological study was possible. Epidemiologists on the panel agreed that having monthly exposure data was the goal for the study, and that levels of uncertainty needed to be explicitly identified. Panel members concurred that the goal of the Hadnot Point water modeling should be the estimation of monthly average concentrations with associated confidence intervals. Many panel members stated that this was a feasible and attainable goal, with two water-distribution system experts on the panel concurring that it was possible to calculate monthly probabilistic estimates of concentrations reaching customers of the water systems. Two panelists suggested that the study consider more than in utero and 1-year-old subjects, however.

4. Panel members indicated that modeling the time when the Hadnot Point and Holcomb Boulevard systems were interconnected will be difficult. They recommended that ATSDR use a detailed water-distribution system model to investigate extended-period simulation scenarios over several months to accomplish this effort.

5. Panel members acknowledged that important information gaps exist and that cooperative efforts with the Department of the Navy (DON) should continue to ensure that ATSDR has all of the data and documentation necessary to accurately and efficiently complete its water-modeling activities and epidemiological study.

6. Panelists recommended that ATSDR and its cooperator continue investigating the use of control-theory concepts for reconstructing historical concentrations at contaminated water-supply wells.

7. Panel members recommended that ATSDR convene technical groups of three to four experts periodically during the course of future water-modeling activities to provide the agency with more frequent technical input.

8. ATSDR had proposed a project completion date of December 2009; panelists estimated that at least one additional year would be necessary to finish the modeling activities and to provide exposure estimates to the epidemiological study team.

In August 2009, ATSDR distributed a draft version of this meeting report and the verbatim transcripts to expert panel members and representatives of the community assistance panel (CAP), the DON, the U.S. Environmental Protection Agency (USEPA), USMC (headquarters and Camp Lejeune), ATSDR, Eastern Research Group, Inc. (ERG), and Georgia Institute of Technology (Ga. Tech). ATSDR considered all comments received during the allotted time period (August–October 2009). Changes deemed appropriate were incorporated, and are reflected in this final version of the meeting report.

1.0 Introduction

1.1 Background

Operations at U.S. Marine Corps (USMC) Base Camp Lejeune, located near Jacksonville, Onslow County, North Carolina (Figure 1) began during the early 1940s and continue to the present day. Presently (2009), about 150,000 people live and work on the base, comprising active duty military personnel, military family members, civilian employees, and retirees. The base population is relatively young, with approximately two-thirds of the active duty personnel and their dependents under 25 years of age. Fifteen different housing areas and six schools are located at the base. Typically, Marines and their families live on base for an average of 2 years. Water-distribution systems serving family housing and bachelor quarters within the Hadnot Point and Holcomb Boulevard service areas (Figure 2) were constructed and placed in service as base operations expanded and population increased: Hadnot Point during the early 1940s, Tarawa Terrace during 1952, and Holcomb Boulevard during June 1972. Prior to June 1972, the Hadnot Point water treatment plant (WTP) supplied water to areas currently served by the Holcomb Boulevard WTP. Historically, eight water-distribution systems provided finished water to on-base barracks and family housing units. As shown in Figures 1 and 2, these areas included Hadnot Point, Tarawa Terrace, Holcomb Boulevard, Courthouse Bay, Rifle Range, Onslow Beach, Montford Point/Camp Johnson, and New River Air Station. Organic solvent contamination was detected in three of the eight water treatment plants serving the base: Tarawa Terrace,[2] Hadnot Point, and Holcomb Boulevard (Figure 2). During on-base sampling in 1980–1985, volatile organic compounds (VOCs) were detected in Tarawa Terrace and Hadnot Point water-supply wells and in their respective WTPs. The main contaminant detected at Tarawa Terrace was tetrachloroethylene (PCE).

[2] ATSDR convened an expert panel in March 2005 to review the agency's water-modeling activities for Tarawa Terrace. A copy of that meeting report (Maslia 2005), which includes additional background information, can be found at *http://www.atsdr.cdc.gov/SITES/LEJEUNE/panel_report_groundwater.html*.

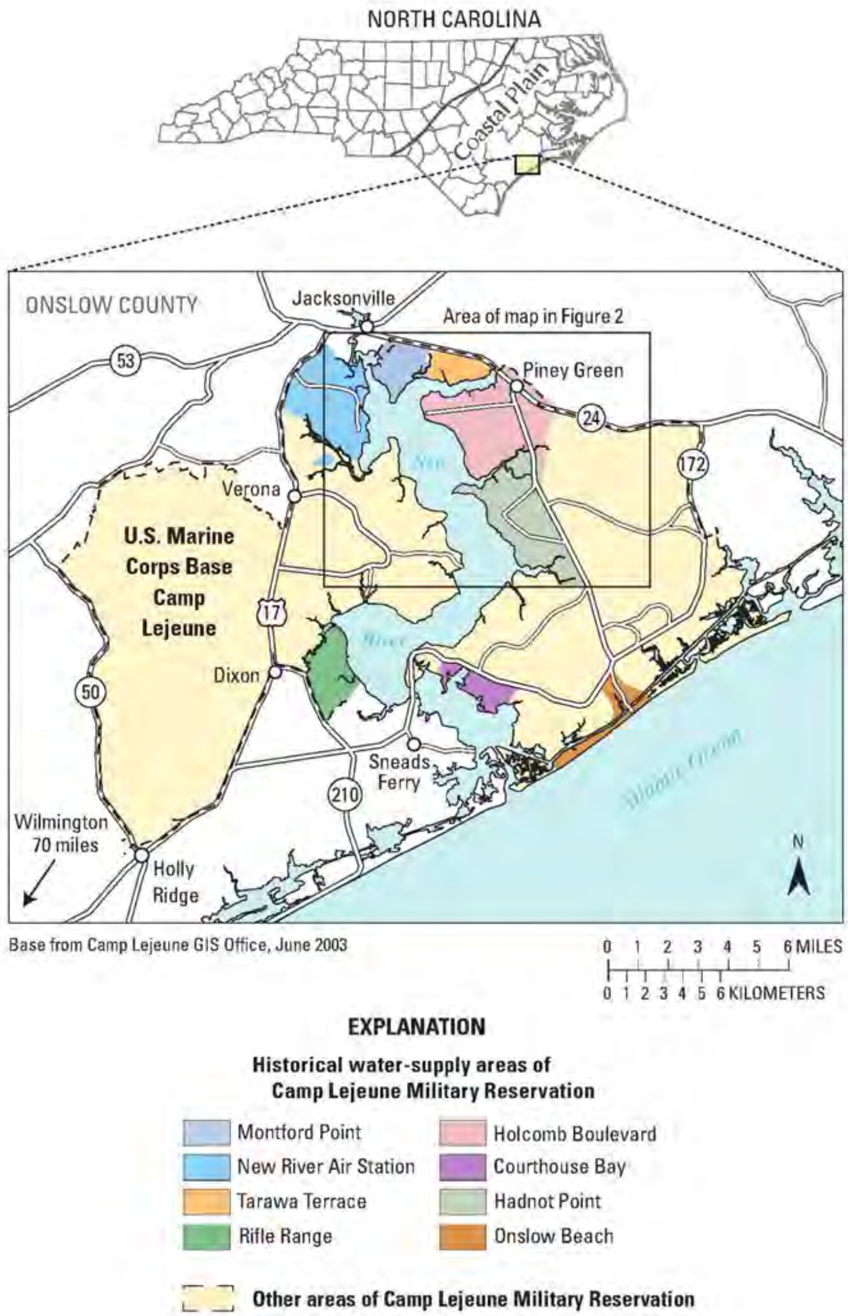
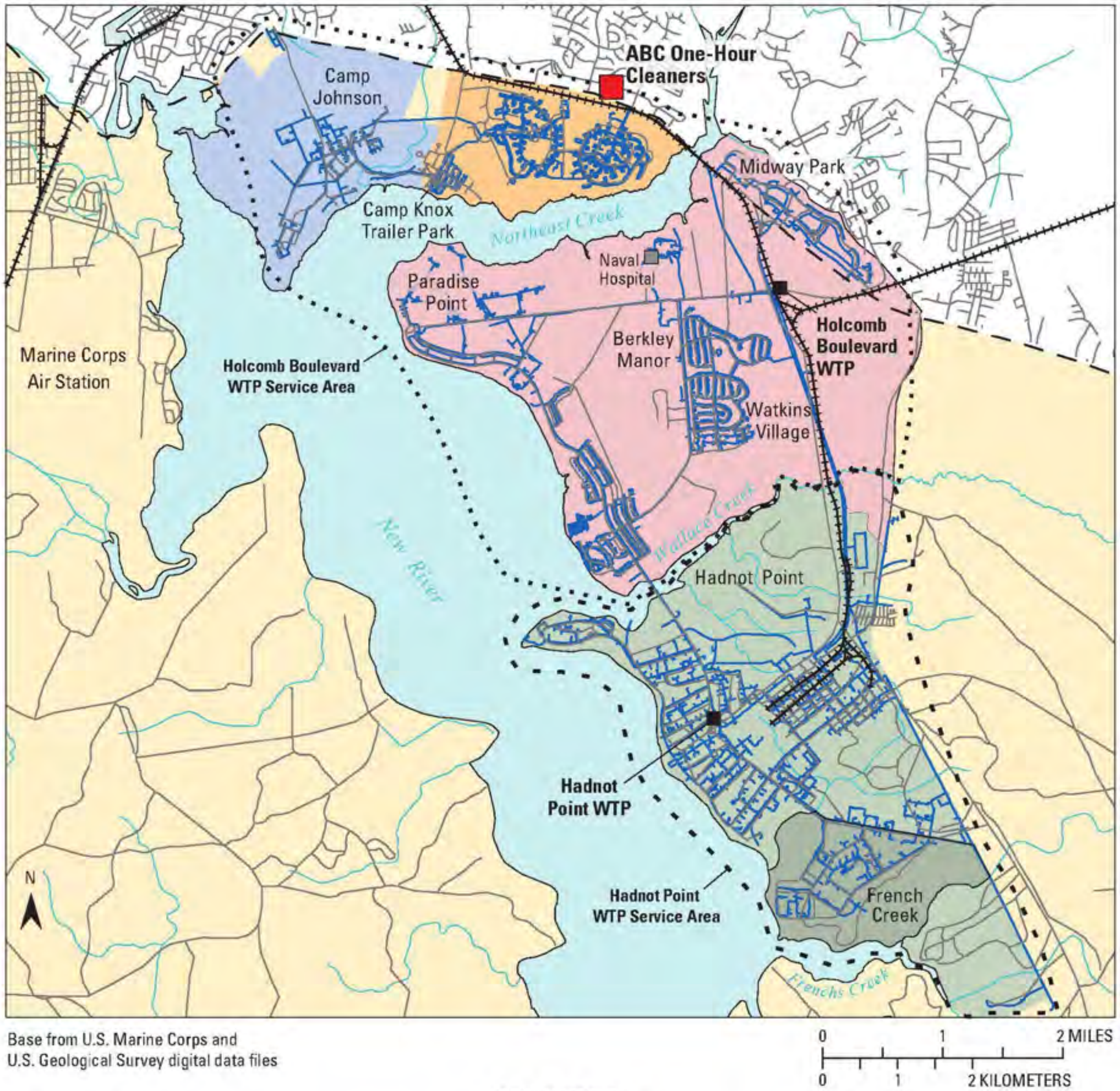


Figure 1. Location of U.S. Marine Corps Base, Camp Lejeune, North Carolina [modified from Maslia et al. 2007].



Base from U.S. Marine Corps and
U.S. Geological Survey digital data files

EXPLANATION

Historical water-supply areas of Camp Lejeune Military Reservation

- Montford Point
- Tarawa Terrace
- Holcomb Boulevard
- Hadnot Point

Other areas of Camp Lejeune Military Reservation

Water pipeline—2004

Water treatment plant (WTP)—
Begin operation dates:
Hadnot Point—1942
Holcomb Boulevard—June 1972

Figure 2. Historical water-supply areas and water-distribution systems serving Hadnot Point, Holcomb Boulevard, and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

1.0 Introduction

Trichloroethylene (TCE) was the primary contaminant identified in Hadnot Point water-supply wells and at the WTP. Other contaminants identified at Hadnot Point included benzene, PCE, dichloroethylene (DCE),[3] and vinyl chloride (VC). By March 1985, all highly contaminated water-supply wells were taken out of continuous service. Residents of the Holcomb Boulevard WTP service area were intermittently provided with contaminated drinking water under two circumstances:

1. finished water from the Hadnot Point WTP was intermittently used during periods of no or minimal rainfall, in late spring and early summer, to supplement water supplied by the Holcomb Boulevard WTP during 1972–1985, and

2. during January 29–February 7, 1985, the reservoir at the Holcomb Boulevard WTP was accidently contaminated with a refined petroleum product, so finished water from the Hadnot Point WTP was used.

During the 10-day period of interconnection when the Holcomb Boulevard WTP was out of service, VOC contamination was detected in drinking water throughout the Holcomb Boulevard service area, with the highest concentrations observed at the Berkeley Manor Elementary School (TCE ≤1,148 micrograms per liter [μg/L]; 1,1-DCE ≤407 μg/L).

Accidental spills, leaks from underground and above-ground storage tanks (USTs and ASTs), and poorly managed waste disposal practices probably contributed to the contamination of the Hadnot Point water-supply wells and subsequently to Hadnot Point WTP finished water. Precisely when various Hadnot Point WTP supply wells were contaminated is unknown; however, VOCs were first detected in raw and finished water from the Hadnot Point WTP during 1982. Contaminated finished water at one building served by the Hadnot Point water-distribution system contained TCE concentrations ranging from 5 μg/L to 1,600 μg/L during 1984. By February 1985, most of the highly contaminated water-supply wells providing raw water to the Hadnot Point WTP were taken out of continuous service. Water-supply well HP-645, which supplied the Holcomb Boulevard WTP, was found to be contaminated with benzene during November 1986 and was removed from service at that time. However, well HP-645 probably supplied benzene-contaminated water to the Holcomb Boulevard WTP for an unknown period prior to November 1986 at unknown concentrations. Two samples collected in well HP-645, on November 6, 1986 and February 17, 1987, contained benzene concentrations of 20 and 290 μg/L, respectively. A chronology of water-supply well operations during the period 1942–2008 and those water-supply wells with documented contamination are shown in Figure 3. Data presented in this figure are correct as of the date of this report, but may be subject to change.

In 1997, ATSDR published a health assessment for Camp Lejeune and recommended that a follow-up health study be conducted to evaluate the potential risks to infants and children exposed in utero to chlorinated solvents known historically to be present in on-base drinking water. In response to this recommendation, ATSDR conducted a study of adverse birth outcomes in 1998. ATSDR linked Onslow County, North Carolina, birth certificates from 1968–1985 with base family housing records to evaluate possible associations between maternal exposure to base drinking-water contaminants and pre-term birth (<37 weeks gestational age), mean birth weight deficit, and small for gestational age (SGA) occurrences. The study found that exposure to PCE in drinking water from the Tarawa Terrace WTP was related to an elevated risk of SGA for mothers older than 35 years who experienced two or more prior fetal losses. The study also found that an elevated risk of SGA, though only among male infants, was associated with exposure to TCE from the Hadnot Point WTP. The study was unable to evaluate birth defects and childhood cancers, however. Additional details pertaining to ATSDR's epidemiological studies at Camp Lejeune are provided in the health study presentation on the CD–ROM accompanying this report.

[3] Dichloroethylene (DCE) has various isomers, all of which have been documented in water-quality samples at Camp Lejeune. The isomers include 1,1-DCE, 1,2-*c*DCE, and 1,2-*t*DCE. Refer to the Glossary and Abbreviations for complete definitions.

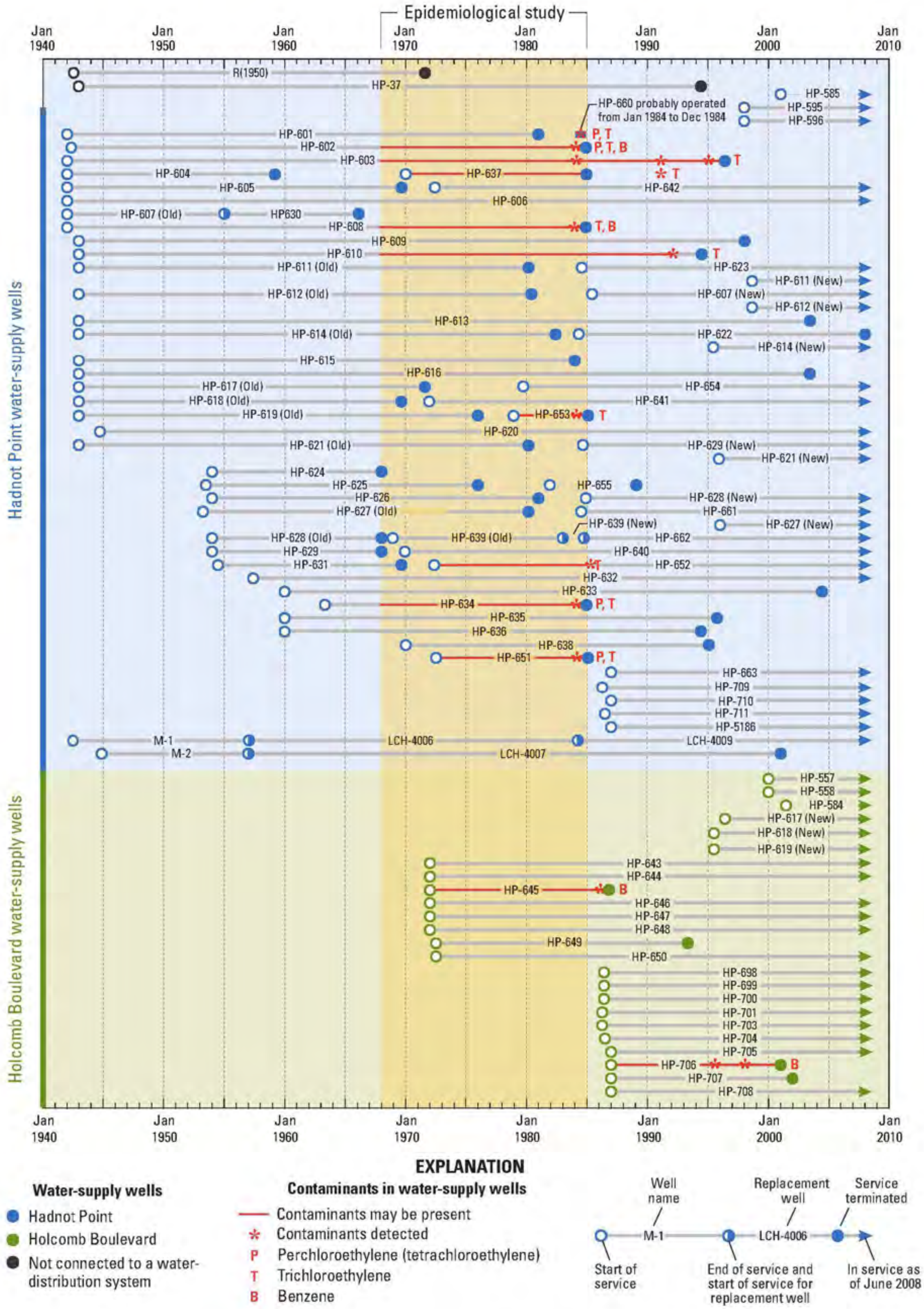


Figure 3. Chronology of Hadnot Point and Holcomb Boulevard water-supply well operations, 1942–2008, and contaminated water-supply wells, U.S. Marine Corps Base Camp Lejeune, North Carolina.

During the 1998 study, ATSDR presumed that the Holcomb Boulevard water-distribution system operated during the entire study period (1968–1985) and provided uncontaminated finished drinking water to the Holcomb Boulevard family housing area. However, during the historical reconstruction of the Tarawa Terrace system, ATSDR learned that (1) the Holcomb Boulevard WTP did not begin operations until June 1972, (2) Holcomb Boulevard areas of the base were serviced with finished drinking water from the Hadnot Point WTP prior to June 1972, and (3) even after the Holcomb Boulevard WTP came online, contaminated finished drinking water from the Hadnot Point WTP was intermittently supplied to the Holcomb Boulevard service area during dry late spring and early summer months. Thus, families living in the Holcomb Boulevard WTP service area during these periods were mistakenly considered unexposed for the 1998 study. ATSDR plans to reanalyze these study data using monthly contaminant estimates obtained from the historical reconstruction of base water system operations.

Currently, ATSDR is conducting a case-control epidemiological study to evaluate exposure in utero and up to 1 year of age to VOC-contaminated drinking water at the base during the period 1968–1985. The study will assess specific birth defects (e.g., neural tube defects, cleft lip, cleft palate) and childhood cancers (e.g., childhood leukemia) and is being implemented using a multi-step process that includes these steps:

1. a review of scientific literature to identify specific birth defects and childhood cancers associated with exposure to VOC-contaminated drinking water;
2. a telephone survey to identify potential cases;
3. a medical records search to verify the diagnoses of reported cases; and
4. a case-control study to interview parents regarding potential exposures and risk factors, and to link these data to exposure estimates obtained via water modeling.

ATSDR has completed the literature review, the telephone survey, and the verification of self-reported diagnoses. No maternal, *in utero*, or infant exposure data exist, and only very limited historical contaminant concentration data are available to support the epidemiological study. Therefore, ATSDR is conducting water-modeling activities to estimate the distribution and concentration of contaminants in groundwater and in water-distribution systems by housing location at Camp Lejeune. Once completed, simulation results from water-modeling analyses for Tarawa Terrace, Hadnot Point, and Holcomb Boulevard will be used by ATSDR's epidemiologists to quantify the estimates of historical exposures for its study population. The health study team will link water-modeling results (monthly contaminant concentrations) with the interview data to assign exposure status and contamination levels to the cases and controls. Water-modeling team members are blinded as to the status (exposed or unexposed) of the cases and controls.

ATSDR's modeling team is currently (2009) conducting water-modeling analyses for the Hadnot Point and Holcomb Boulevard water-distribution systems. As of March 2009, the team had completed data analyses and statistical and fate property analyses for Installation Restoration Program (IRP) sites, and had conducted preliminary groundwater and water-distribution system modeling. To obtain expert technical advice regarding the best approaches and methods to historically reconstruct specific contaminant concentrations delivered by the Hadnot Point and Holcomb Boulevard WTPs, ATSDR convened an expert panel in Atlanta, Georgia, on April 29–30, 2009. ATSDR requested the 13 panel members to evaluate, discuss, provide feedback, and offer recommendations to help the agency evaluate the information, data, and modeling methods to be applied in analyzing the base drinking-water supplies.

1.2 Meeting Organization

Panelists for the 2-day meeting included 13 experts in areas of geohydrology, groundwater hydraulics, fate and transport analysis, water-distribution system analysis, numerical modeling, model calibration methods, uncertainty and probabilistic analysis methods, epidemiology, and public health. The panel chair was Dr. Robert M. Clark, an independent consultant who worked as an environmental engineer at the U.S. Public Health Service (USPHS) and the U.S. Environmental Protection Agency (USEPA) until retiring in 2002.

Prior to the meeting, panel members received the overall charge and background information consisting of the summary report from ATSDR's expert panel meeting held March 28–29, 2005, as well as documentation on ATSDR's completed and published water-modeling activities conducted for the Tarawa Terrace area of the base. Panel members also were provided with draft technical documentation that included the status of current analyses (Hadnot Point, Holcomb Boulevard, and vicinity), information on data discovery and data analyses, modeling analyses conducted to date, and other information to assist the panelists with their evaluation of ATSDR's current data analyses and water-modeling activities.[4]

During the meeting, representatives from ATSDR, its cooperative partner, the Multimedia Environmental Simulations Laboratory (MESL) at the Georgia Institute of Technology (Ga. Tech), and its contractor, Eastern Research Group, Inc. (ERG, Inc.), delivered presentations on the following topics:[5]

1. an overview of the agency's 1998 study on adverse pregnancy outcomes and the current case-control epidemiological study;
2. a summary of water-modeling activities at Tarawa Terrace, Hadnot Point, Holcomb Boulevard, and vicinity;
3. a summary of contaminant source areas and data for Hadnot Point and vicinity;
4. an overview of well capacity histories for Hadnot Point and Holcomb Boulevard;
5. an outline of the approach for computations of subsurface contaminant mass for Hadnot Point and vicinity;
6. a detailed presentation on the development and application of the control-theory methodology proposed for reconstructing historical contaminant concentrations at contaminated water-supply wells;
7. an approach to numerical groundwater-flow and contaminant fate and transport modeling; and
8. preliminary modeling results for the historical reconstruction of the Hadnot Point and Holcomb Boulevard water-distribution systems.

[4] The overall charge and introductory materials were sent to panel members on February 5, 2009. Technical documentation was sent to panel members on March 20, 2009. However, owing to budgetary constraints, non-government employee panel members were instructed not to begin work until April 2, 2009.

[5] Copies of the presentations can be found on the CD-ROM included with this report.

Throughout the meeting and during the presentations, panelists asked detailed questions, brought up potential issues that needed to be recognized and addressed, offered opinions on potential approaches, and responded to the agency's charge questions. Prior to the meeting's end, each panel member was asked to provide comments and recommendations regarding the charge questions and the information provided before and during the meeting. A summary of panelist recommendations and ATSDR's responses are presented in Section 6. Attendees for part or all of the meeting included representatives from USMC Camp Lejeune and Headquarters, a representative from the Navy Marine Environmental Health Center who sits on the ATSDR Camp Lejeune CAP, a representative from the Naval Facilities Engineering Command (NAVFAC-Atlantic), members of the ATSDR Camp Lejeune CAP, individuals from the public, a representative from USEPA Headquarters, a USEPA consultant, ATSDR staff members, and a court reporter.

This report summarizes the presentations, discussions, and recommendations from the 2-day expert panel meeting. Section 2.0 provides opening remarks, including a statement by the chair and an overview of the epidemiological study activities. Section 3.0 summarizes the presentations given by members of ATSDR's water-modeling team, including water-modeling activities conducted to date, summaries of proposed methods for modeling contaminant concentrations, and preliminary results obtained thus far. Section 4.0 presents the panel's discussions, questions, potential issues raised, and general recommendations. Section 5.0 summarizes information presented during the public comment period of the meeting. Section 6.0 summarizes the panelists' recommendations and provides ATSDR's responses to the recommendations. Appendix A includes the agenda, charge to the panel, and scope of the panel. Appendix B lists the panel members, presenters, and observers. Appendix C presents the statement made during the public comment period by a CAP member and former Marine, Jerome M. Ensminger. Appendix D contains the Department of the Navy's statement to the panel, presented by Dr. Dan Waddill, during the public comment period of the meeting. Appendix E presents the premeeting comments submitted by the panel members based on draft technical documentation received prior to the meeting. Appendix F contains two- to three-page *curricula vitae* for the panel members. A CD–ROM included on the inside back cover of this report contains a copy of this summary report, the two-volume verbatim meeting transcripts, and copies of the presentations made by ATSDR staff, their contractor (ERG, Inc.), and cooperator (Ga. Tech) to the expert panel.

2.0 ATSDR Objectives and Goals

2.1 Opening Remarks

Tom Sinks, Deputy Director, NCEH/ATSDR

Dr. Tom Sinks, Deputy Director for the National Center for Environmental Health (NCEH)/ATSDR, welcomed panel members and introduced the panel chair. Dr. Sinks explained that environmental epidemiologists were concerned about correctly defining the possible drinking-water exposures at Camp Lejeune. Although they did not have drinking-water information from measurements at Camp Lejeune, ATSDR would do its best to estimate potential exposure concentrations. He noted that transparency is important to ATSDR and that the agency was determined to obtain the best information possible to complete this study in a timely fashion. Following his opening remarks, Dr. Sinks introduced Dr. Robert M. Clark, a former environmental engineer at the USPHS and USEPA who now works as an independent consultant.

2.2 Statement by the Chair

Robert M. Clark, Panel Chair

Dr. Robert M. Clark read a statement explaining that the panel was charged with considering the appropriateness of ATSDR's approach, methods, and time requirements related to water-modeling activities (Appendix A). He noted the importance of understanding that the water-modeling activities for the Hadnot Point and Holcomb Boulevard areas are in the early stages of analysis. As such, the data, interpretations, and modeling methodology are subject to modifications, partly based on input provided by panel members during this 2-day meeting. Dr. Clark emphasized the desire for fair and open discussion, noting the objective to obtain maximum input from the experts during this meeting. Following his statement, Dr. Clark had the panel members introduce themselves and briefly summarize their backgrounds and affiliations. A list of panel members and their affiliations is provided in Appendix B, and a *curriculum vitae* for each panel member is provided in Appendix F.

2.3 Introduction of ATSDR Study Team and Stakeholders

Morris L. Maslia, Project Officer, ATSDR

Mr. Morris L. Maslia, a research environmental engineer and project officer with the Exposure-Dose Reconstruction Program within ATSDR's Division of Health Assessment and Consultation (DHAC), introduced members of the ATSDR study team. The epidemiological study team includes three representatives from ATSDR's Division of Health Studies: Frank Bove, senior epidemiologist and co-principal investigator; Perri Ruckart, epidemiologist and co-principal investigator; and Carolyn Harris, public health analyst. The water-modeling team includes four representatives of ATSDR's DHAC: Morris L. Maslia, research environmental engineer and project officer; Barbara Anderson, environmental health scientist; René J. Suárez-Soto, environmental health scientist; and Jason B. Sautner, environmental health scientist. The water-modeling study team also includes an ATSDR consultant, Robert E. Faye, Robert E. Faye and Associates (a sub-contractor to ERG, Inc.), and an ATSDR cooperator, Dr. Mustafa M. Aral, Director of the Multimedia Environmental Simulations Laboratory (MESL) at the Georgia Institute of Technology. Mr. Maslia also introduced stakeholders who were present, including representatives from the U.S. Marine Corps (Camp Lejeune and headquarters), the Department of the Navy (DON), CAP members, and a USEPA contractor (Shaw, Inc.).

2.4 Summary of ATSDR's Epidemiological Health Study

Frank Bove and Perri Ruckart, Principal Investigators, ATSDR

Dr. Frank Bove and Ms. Perri Ruckart provided information on the agency's 1998 study on adverse pregnancy outcomes (described in Section 1.1) and on the current case-control study (briefly described in Section 1.1 with additional details provided below). A copy of Dr. Bove's and Ms. Ruckart's presentation to the expert panel is available on the CD–ROM accompanying this report.

Current Case-Control Study

Currently (2009), ATSDR is conducting a case-control study to determine whether exposure to VOCs in base drinking water is associated with specific birth defects and childhood cancers. Based on the available scientific literature, ATSDR is evaluating the following outcomes:

1. neural tube defects (NTD),
2. oral cleft defects (cleft lip and cleft palate),
3. childhood leukemia, and
4. childhood non-Hodgkin's lymphoma.

ATSDR surveyed parents of 12,598 eligible children out of 16,000–17,000 estimated births during 1968–1985 to identify potential cases of the selected adverse outcomes among births occurring during 1968–1985 to mothers who had resided on-base at any time during their pregnancy. Based on the survey findings, the following cases of disease were identified: NTDs (35), oral cleft defects (42), and childhood cancers (29). At this time, ATSDR has completed verifying the cases obtained by the survey. Of the total 106 reported cases of NTDs, oral clefts, and childhood cancers, 52 have been confirmed. ATSDR has also completed interviewing parents of 548 controls to obtain information on maternal water consumption habits, maternal residential history, maternal exposures during pregnancy, and parental risk factors. Base family housing records were reviewed to verify the dates and location of the mother's reported residence on base.

Data Analysis

Dr. Bove summarized the epidemiological study team's proposal for data analysis. He indicated that separate analyses will be conducted for NTDs, oral cleft defects, and childhood leukemia/non-Hodgkin's lymphoma. The analyses will evaluate both continuous and categorical drinking-water contaminant variables, using smoothing methods to suggest categorical variable cutpoints, and analyzing each contaminant separately as well as the joint effects of the contaminants. Parameters will vary depending on when a particular effect is expected to be associated with contaminant exposure. For all three effect groups being investigated, ATSDR will evaluate the average and maximum contaminant level over the first trimester and the average and maximum contaminant level during the period 3 months prior to date of conception. Per-effect differences in analyses will include analyzing the average level in the first month of pregnancy for NTDs, the average level in the second month of pregnancy for oral cleft defects, and the average and maximum contaminant levels during the first year of the child's life and the cumulative exposure during the pregnancy and first year of child's life for confirmed cases of childhood cancers.

Dr. Bove presented an example of data for PCE contamination levels from Tarawa Terrace by gestational month. He noted that the variability in these data levels illustrates why monthly estimates of exposure are needed for the epidemiological study. The study team would use logistic regression to compute unadjusted and adjusted results and calculate 90% confidence intervals. The final model would include potential confounders that contribute to a ≥10% change in the parameter estimate for the exposure variable. The team also would evaluate categorical variables based on water usage data obtained from interviews, both individually and in combination with the estimated contaminant levels. A sensitivity analysis would be performed to assess the effect of exposure misclassification. The team is considering a secondary analysis, including cases and controls with incomplete residential histories or cases that could not be confirmed by medical records. Overall, the interpretation of results will be based on

1. magnitude of association,
2. exposure-response relationship,
3. biological plausibility, and
4. consistency with other studies.

3.0 Summary of Water-Modeling Activities

3.1 Overview of Water-Modeling Activities

Morris L. Maslia, Project Officer, ATSDR

Mr. Maslia outlined the four goals and objectives of ATSDR's water-modeling activities for supporting the current health study. (A copy of Mr. Maslia's presentation to the expert panel is available on the CD–ROM accompanying this report.) These goals, in order of preference and complexity, are to

1. determine the arrival dates of contaminants at water-supply wells,
2. identify the distribution of contaminants by housing location,
3. estimate the monthly mean concentrations, and
4. assess the reliability of and confidence in water-modeling results.

Mr. Maslia presented a map of the epidemiological study areas, noting that the study focuses on three housing areas: Tarawa Terrace, Holcomb Boulevard, and Hadnot Point (Figure 2). He presented a generalized chronology of events, including the dates that each of the three water systems operated: Hadnot Point, 1942–present (2009); Tarawa Terrace, 1952–1987; and Holcomb Boulevard, June 1972–present (2009).

Mr. Maslia explained that ATSDR epidemiologists had initially assumed that the Tarawa Terrace and Hadnot Point populations were continuously exposed to different sources of contaminated drinking water from 1968–1985 while the Holcomb Boulevard population was unexposed. However, based on documents and articles provided by the USMC to the agency, ATSDR became aware that the Holcomb Boulevard WTP did not come online until June 1972; therefore, the Hadnot Point WTP provided contaminated drinking water to the Holcomb Boulevard area from 1968–1972. Mr. Maslia further explained that booster pump 742 and the Marston Pavilion valve[6] acted as "interconnections" between the two water-distribution systems. As a result of these interconnections, even after the Holcomb Boulevard WTP came online in June 1972, when the booster pump was operated or the Marston Pavilion valve was opened intermittently during dry periods of late spring to early summer, there was mixing of contaminated Hadnot Point drinking water with Holcomb Boulevard distribution system water.

3.1.1 Completed Water-Modeling Activities at Tarawa Terrace

ATSDR has completed its water-modeling activities for the Tarawa Terrace base housing area, and all of the associated reports are available online at *http://www.atsdr.cdc.gov/SITES/LEJEUNE/watermodeling.html*. An expert panel held in March 2005 provided recommendations dealing with five broad categories, which were implemented and discussed in Chapter A of the report:

1. data discovery,
2. event chronology,
3. groundwater modeling for Tarawa Terrace,
4. data analyses for Hadnot Point, and
5. water-distribution analyses.

[6] The verbatim transcript refers to the "Wallace Creek" valve when discussing the interconnection. To clarify the verbatim transcript, it was the "Marston Pavilion" valve that was intermittently opened during periods of interconnection.

There were three main conclusions from the modeling effort at Tarawa Terrace. First, the modeling results indicated that calibrated models are useful for the epidemiological study with regards to groundwater flow, contaminant fate and transport, and mixing. Second, the concentrations measured during the 1980s are representative of high concentrations experienced over many years; there were no indications that finished water had higher concentrations. Third, the conclusions from this effort would not have been possible without using groundwater-modeling techniques.

3.1.2 Status of Activities and Analyses at Hadnot Point, Holcomb Boulevard, and Vicinity

As of March 2009, ATSDR had nearly completed its analyses of IRP site data, a draft report of IRP data analyses, and statistical and fate property analyses. These analyses do not, however, incorporate information from more than 150 UST reports that ATSDR became aware of in March 2009. ATSDR is about 10 percent complete with its groundwater-flow modeling. In addition, for the water-distribution system modeling, "all-pipes" network models have been calibrated for Hadnot Point and Holcomb Boulevard, and initial simulations have been conducted to consider a number of different Hadnot Point and Holcomb Boulevard interconnection scenarios. Currently, ATSDR has data for wells and boreholes, water-level measurements, groundwater samples analyzed for chlorinated solvents (PCE, TCE, DCE, and VC) and BTEX (benzene, toluene, ethylbenzene, and xylenes), water-supply well tests, and monitor well tests.

3.2 Summary of Contaminant Source Areas and Data: Hadnot Point, Holcomb Boulevard, and Vicinity

Robert E. Faye, Civil Engineer/Hydrologist, Robert E. Faye and Associates, Inc.

Mr. Robert E. Faye has assisted ATSDR in locating data, processing data, and writing one of the draft data reports for Hadnot Point, Holcomb Boulevard, and vicinity. IRP sites referred to by Mr. Faye and subsequent ATSDR staff are shown in Figure 4. Mr. Faye's presentation is summarized below. (A copy of Mr. Faye's presentation to the expert panel is available on the CD–ROM accompanying this report.)

3.2.1 Available Pumpage Data

To a large degree, the available data allow ATSDR to assess pumping schedules. The available data include

1. daily operations schedule for Hadnot Point WTP individual water-supply wells from November 28, 1984 to February 4, 1985;
2. hours pumped and corresponding pumping rates for Hadnot Point and Holcomb Boulevard WTP individual supply wells for October 1988 to March 1989;
3. total gallons pumped, average pumping rate, average daily withdrawal, and percent of time inactive for Hadnot Point and Holcomb Boulevard WTP individual supply wells for 1993; and
4. daily log for well pumps indicating on/off status of individual supply wells to the Hadnot Point and Holcomb Boulevard WTPs for January 1998 to June 2008.

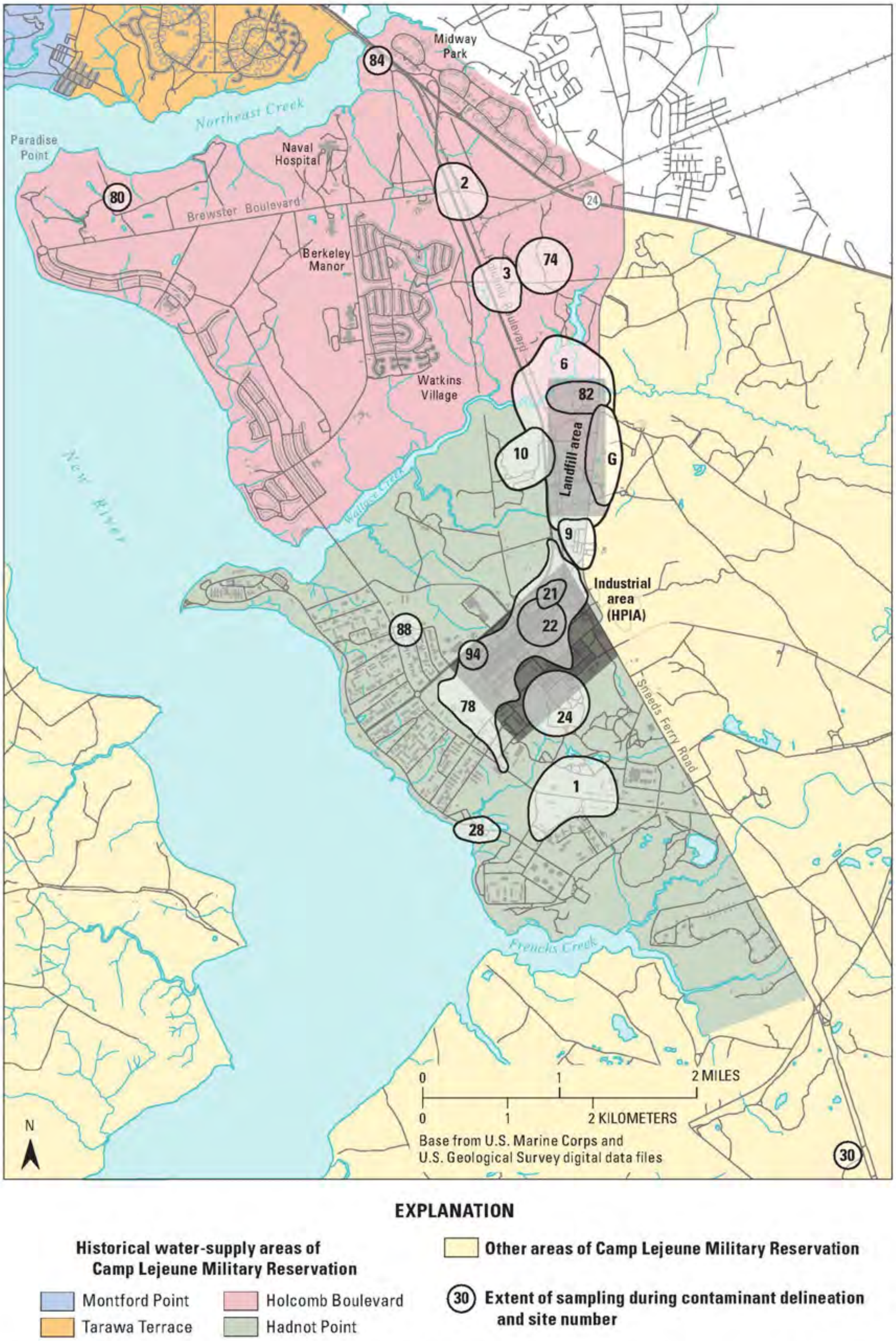


Figure 4. Location of contamination sites assessed by ATSDR, Hadnot Point, Holcomb Boulevard, and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina [ATSDR, Agency for Toxic Substances and Disease Registry].

3.2.2 Data for Water Treatment Plant: Supplied and/or Delivered Water

Based on the available data, ATSDR is in a good position to derive WTP annual delivery rates and probably monthly delivery rates. The available data include

1. annual delivery rates for Hadnot Point WTP for 1942–1998;
2. annual delivery rates for Holcomb Boulevard WTP for 1975–1998;
3. monthly rates of supplied raw water/delivered treated water to Hadnot Point and Holcomb Boulevard WTPs for September 1955–January 1957, January 1980–December 1984, January 1982–December 1993, and January 1987–February 1989; and
4. daily rates of supplied raw water/delivered treated water for Hadnot Point and Holcomb Boulevard WTPs, January 1995–May 1999 and January 2000–December 2005.

3.2.3 Contamination Analysis

Mr. Faye presented slides (available on the CD–ROM included with this report) indicating contaminated subareas within the study area. He pointed out three subsurface investigation sites: the landfill area, the Hadnot Point industrial area (HPIA), and Site 88 (Figure 4). Maps shown as posters at the meeting showed concentration data of PCE, TCE, and benzene in groundwater within these investigation areas. Additional maps and graphs demonstrated the ranges of contamination and provided insights into the depths of the contamination for the aforementioned contaminants. Mr. Faye explained that there was a massive spill of BTEX[7] at the HPIA, which went down to 150 feet (ft) and represents a major plume system.

3.3 Well Capacity History: Hadnot Point and Holcomb Boulevard

Jason Sautner, Environmental Health Scientist, ATSDR

Mr. Saunter noted that ATSDR is evaluating and analyzing water-supply well data for Hadnot Point and Holcomb Boulevard. A brief summary of his presentation is included below. (A copy of Mr. Sautner's presentation to the expert panel is available on the CD–ROM accompanying this report.)
An abundance of data sources is being evaluated to obtain detailed information on more than 100 water-supply wells so that ATSDR can create a timeline of how wells operated when they were in service (see Figure 3 for a chronology of water-supply well operations). Data include driller logs, well capacity[8] tests, well construction drawings, operation records, and other information sources. Additional documentation sources include various types of lists (i.e., well data, raw water supply, and building dimensions), operational records, water level tables, transmittal and correspondence letters, and other documents and reports. Daily logs also have been searched to glean the well pump status for each day of each month from 1998–2008. An example of a well capacity history was presented, which showed the date the well was put into service, the well capacity in gallons per minute (gpm), the operational status, and the data source used to obtain the information. Also presented was an example of a daily log for a well pump, which identified the pump status (i.e., on/off) and was used to determine the monthly adjusted capacities from 1998–2008. An example adjusted monthly capacity[9] table

[7] The verbatim transcript refers to a "massive spill of benzene" at the HPIA. Benzene is one component of BTEX. During the meeting, Mr. Faye used the term benzene because he was referring to a map showing benzene sample concentrations and a graph showing benzene concentrations correlated with sample depths.

[8] The term "well capacity" used throughout this report and the verbatim transcript refers to the estimated pumping rate.

[9] The term "adjusted monthly capacity" used throughout this report and the verbatim transcript refers to the estimated average monthly pumping rate.

included the date (i.e., month/year), number of days pumped during the month, the capacity in gpm, gallons pumped during the month, number of days in the month, and the adjusted capacity in gpm. In summary, ATSDR is creating well capacity histories for each water-supply well to find historical trends of well pumpage for the Hadnot Point and Holcomb Boulevard water-distribution systems.

3.4 Subsurface Mass Computation: Hadnot Point, Holcomb Boulevard, and Vicinity

Barbara Anderson, Environmental Health Scientist, ATSDR

Ms. Anderson explained that ATSDR is using groundwater contaminant data to compute the estimated contaminant mass in groundwater at Hadnot Point, Holcomb Boulevard, and vicinity. These computations are needed as mass loading inputs for contaminant fate and transport models. A summary of her presentation is provided below. (A copy of Ms. Anderson's presentation to the expert panel is available on the CD–ROM accompanying this report.)

3.4.1 Overview of Subsurface Mass Computation

The purpose of computing contaminant mass is to provide a starting point and lower limit for mass loading in the fate and transport model. This will allow an assessment of plume stability over time, and enable a comparison to other, similar sites. The site locations included within the study area are Site 88, the Landfill Area, and the HPIA (Figure 4). The scope of the mass computation includes PCE, TCE, and benzene. ATSDR was able to obtain results for 2,420 groundwater samples analyzed from 1984 to 2004 for PCE, TCE, DCE, and VC; results for 2,611 samples have been obtained for BTEX components. Samples were collected from 868 wells, boreholes, and hydropunch locations. Based on these data, the maximum observed concentrations in groundwater were 170,000 μg/L for PCE, 180,000 μg/L for TCE, and 36,000 μg/L for benzene.

The general methodology includes the following:

1. select and prepare contaminant data sets,
2. use interpolation techniques to develop two-dimensional concentration distributions,
3. calculate average contaminant concentration across two-dimensional horizontal distributions, and
4. calculate contaminant mass, which equals average concentration across horizontal distribution × planar area of distribution × aquifer thickness × aquifer porosity × conversion factors.

3.4.2 Data Preparation and Interpolation

The data preparation aspect of the mass computation involves selecting datasets by considering the following:

1. horizontal distribution of contaminants (identify sites within the study area),
2. vertical distribution (sample elevations), and
3. temporal distribution (sample collection dates).

If there are multiple detections at the same location, ATSDR typically uses the average rather than the maximum values. In addition, nondetects and censored nondetects are set to zero. Interpolation is being conducted using ordinary kriging, incorporating standard default assumptions within the Surfer® software package, and a 10 ft × 10 ft grid cell size. Illustrations were presented to demonstrate how the four-step methodology was used to compute the TCE mass for the landfill area from 1984 to 1993.

3.5 Reconstruction of Historical Contaminant Concentrations: A Computational Method

Mustafa M. Aral, Director of MESL at the Georgia Institute of Technology

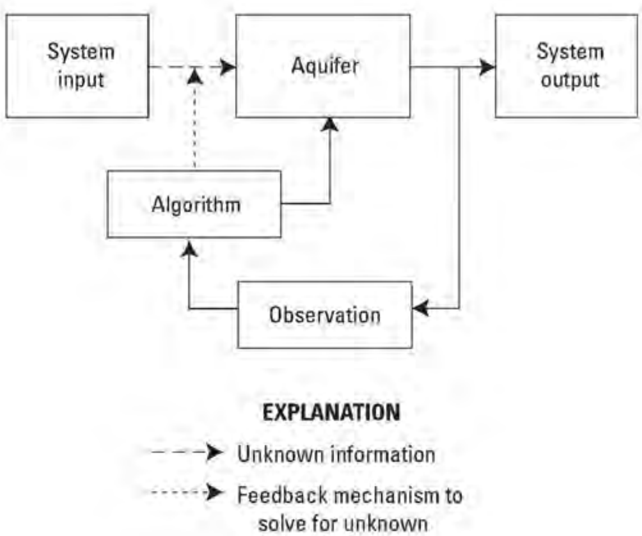
Under a cooperative agreement, Dr. Aral from the Georgia Institute of Technology has been cooperating with ATSDR by analyzing and modeling available data to historically reconstruct contaminant concentrations at Hadnot Point, Holcomb Boulevard, and vicinity. His presentation summarized a screening-level computational method, which he referred to as a "control theory based time-series analysis." A brief synopsis of his presentation follows. (A copy of Dr. Aral's presentation to the expert panel is available on the CD–ROM accompanying this report.)

This analysis theory contains five components: system input, aquifer, observation, algorithm, and system output (Figure 5). The traditional way to look at these types of reconstructions, as was done at Tarawa Terrace, is to use groundwater flow and contaminant fate and transport models and then a mixing or water-distribution system model. However, Dr. Aral proposed a screening-level approach by using the control-theory model for the current study at Hadnot Point, Holcomb Boulevard, and vicinity because of budgetary and time constraints.

It was explained that the accuracy expected from the model is a function of the quality and quantity of the available data. It was proposed that this method be used

1. as a screening-level procedure,
2. for local flow fields (source, geohydrologic framework, and fate),
3. in locations where data are insufficient for a traditional (numerical grid) groundwater model, and
4. for distinct multiple contaminant sources at a site by repeating the process for each contaminant that shows a different fingerprint at the observation points.

Figure 5. Components of the control theory based time-series analysis applied to aquifer analysis.



This proposed method uses monitor well data that are available and applying these data to a local site (e.g., to a landfill). Dr. Aral suggested trying to solve the historical reconstruction problem at water-supply wells by considering the contaminant concentrations at the monitor wells, which are known for several locations. The proposed method was explained and specific details were provided to panel members such as the use of forward and backward time integration.

The applicability of the model was demonstrated by testing the new proposed modeling approach on Tarawa Terrace simulation data. Several graphs were presented, which showed that after pumping stopped, the simulated and reconstructed values were well matched. Overall, the following points were summarized:

1. forward and backward time integration methods could be used to improve the solution,
2. the Kalman filtering method could be introduced to propagate random errors and establish confidence bands on the solutions obtained, and
3. the control theory based time-series analysis method could be applied to Hadnot Point contaminated areas.

3.6 Approach to Numerical Groundwater-Flow and Contaminant Fate and Transport Modeling

René Suárez-Soto, Environmental Health Scientist, ATSDR

Mr. Suárez-Soto described ATSDR's proposed approach for conducting numerical groundwater-flow and contaminant fate and transport modeling for the Hadnot Point and Holcomb Boulevard areas. A summary of his presentation is provided below. (A copy of Mr. Suárez-Soto's presentation to the expert panel is available on the CD–ROM accompanying this report.)

3.6.1 Overview of the Hadnot Point/Holcomb Boulevard Modeling Approach

The groundwater modeling approach will include regional (steady state and transient) and local groundwater-flow modeling and local contaminant fate and transport modeling. In comparison to the model for Tarawa Terrace, the areal extent of this model will be 17 times larger. A map was presented to show the features in the Hadnot Point and Holcomb Boulevard areas that will be incorporated in the regional groundwater-flow modeling effort: specified head (New River), no-flow boundary (topographic divide), general-head boundaries, 8 small creeks, and 100 supply wells. The proposed grid design was displayed, showing 10 model layers and the corresponding geohydrologic units (7 aquifers and 7 confining units).

3.6.2 Proposed Approach

The proposed approach begins with selecting a numerical model. ATSDR plans to run parameter estimation (PEST) software and MODFLOW-2000 for modeling steady-state and transient flow. Then, areas will be selected for local-grid refinement (LGR)—the landfill area, HPIA, and Site 88. For this purpose, ATSDR will need to build local models that can accommodate the many supply wells that are pumping at different times. From these local models, ATSDR will glean the information needed to evaluate the effects of pumping at the LGR boundaries. Finally, ATSDR proposed using PEST and the three-dimensional contaminant fate and transport model, MT3DMS, to conduct contaminant fate and transport simulations for each of the LGR areas.

3.7 Historical Reconstruction of the Water-Distribution Systems: Hadnot Point and Holcomb Boulevard

Jason Sautner, Environmental Health Scientist, ATSDR

Mr. Sautner reviewed possible approaches that ATSDR is evaluating to historically reconstruct contaminant concentrations in the Hadnot Point and Holcomb Boulevard water-distribution systems (Figure 6). His presentation is summarized below. (A copy of Mr. Sautner's presentation to the expert panel is available on the CD–ROM accompanying this report.)

3.7.1 Overview of Water-Distribution Systems

Background information was provided on the Hadnot Point and Holcomb Boulevard WTP service areas. Much of this information was obtained by ATSDR in its field investigation activities during 2004. The Hadnot Point system contains 74 miles of pipelines (~71% polyvinyl chloride [PVC] pipe), with four elevated 300,000-gallon (gal) tanks that deliver approximately 2.3 million gallons per day (MGD) of water. The Holcomb Boulevard system contains 73 miles of pipelines (~67% cast iron [CI] pipes), with three elevated tanks (two 200,000 gal and one 300,000 gal) that deliver approximately 1 MGD of water. The system interconnections occurred via booster pump 742 and the Marston Pavilion interconnect (bypass) valve (Figure 6). Also of interest is that golf courses located near the Paradise Point area were irrigated with potable water from the Holcomb Boulevard water-distribution system during the study time frame.

3.7.2 Modeling Water-Distribution Systems[10]

ATSDR proposes to use EPANET 2 to model the water-distribution systems at Camp Lejeune. EPANET 2 is a public domain code developed by the USEPA. EPANET 2 can simulate spatially distributed contaminant concentrations through the network of pipelines and storage tanks and perform extended period simulation of hydraulic and water-quality behavior. ATSDR plans to model the Hadnot Point and Holcomb Boulevard water-distribution systems as "all-pipes" networks.

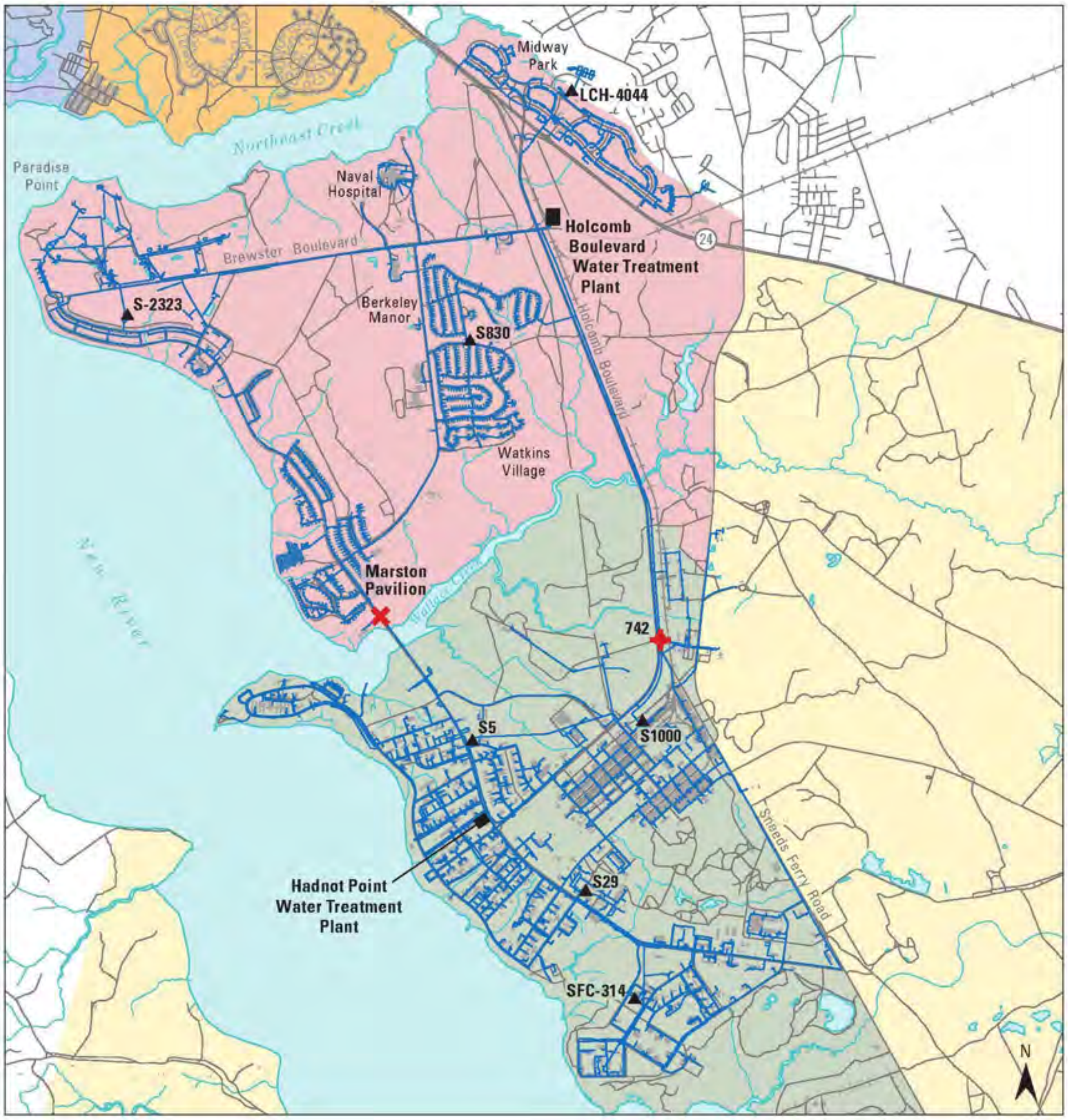
3.7.3 Modeling for the Hadnot Point Water-Distribution System

ATSDR conducted hydraulic and water-quality field tests May 24–27, 2004, by injecting calcium chloride and sodium fluoride directly into the water-distribution system at the Hadnot Point WTP and continuously measuring the concentrations at various locations throughout the water-distribution system. Demand data were aggregated into eight different demand patterns based on type of usage. The PEST model was used to assist with model calibration. A graph of calibration results was presented to show the simulated results for PEST-fitted parameters compared to the field data results.

3.7.4 Modeling for the Holcomb Boulevard Water-Distribution System

ATSDR conducted hydraulic and water-quality field tests on this water-distribution system also, where the fluoride feed was turned off and turned back on at the Holcomb Boulevard WTP for a 21-day test during the period September 23–October 11, 2004. Calibration results were graphically displayed, and the simulation results for PEST-fitted parameters also were compared with field data results.

[10] Results of water-distribution system field investigations and modeling analyses—including the application of PEST—have been published previously by ATSDR (Maslia et al. 2009b, p. 120–130) and are available online at *http://www.atsdr.cdc.gov/sites/lejeune/docs/Chapter1_TarawaTerrace.pdf.*



Base from U.S. Marine Corps and
U.S. Geological Survey digital data files

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

Historical water-supply areas of Camp Lejeune Military Reservation

- Montford Point
- Tarawa Terrace
- Holcomb Boulevard
- Hadnot Point

Other areas of Camp Lejeune Military Reservation

Water distribution

- Water pipeline—2004
- S29 Elevated storage tank and number
- Interconnect valve—Marston Pavillion at Wallace Creek
- Booster pump—742

Figure 6. Location of interconnections between Hadnot Point and Holcomb Boulevard water-distribution systems, U.S. Marine Corps Base Camp Lejeune, North Carolina.

3.7.5 Information for Modeling the Interconnection Periods

Interconnections from the Hadnot Point to the Holcomb Boulevard water-distribution system occurred via the Marston Pavilion (Wallace Creek) interconnect valve and booster pump 742 (Figure 6). Log books were obtained from Camp Lejeune covering the period 1978–1986. Data gaps include 1972–1977, November 1978–November 1979, and August 1980–July 1982. Booster pump 742 operated more frequently in the mid-1980s than in the late 1970s or early 1980s. It was operated when increased demand at Holcomb Boulevard occurred, mostly during dry months in late spring to early summer (i.e., April, May, June, and July). The Marston Pavilion bypass valve was only operated when demand could not be met by using booster pump 742. Opening of the Marston Pavilion valve has been documented to have occurred during the period January 27–February 4, 1985 (9 days), as well as on 9 additional days between 1978 and 1986.

3.7.6 Considerations for Historical Reconstruction

Historical reconstruction results based on water-distribution system modeling were graphically displayed for the Holcomb Boulevard controlling elevated storage tank S-2323, the Berkeley Manor elevated storage tank S-830, and the larger study area to obtain feedback from panel members (see also Maslia et al. 2009b). In the future, ATSDR will consider modeling each month that booster pump 742 was operating, using actual log book data to consider actual occurrences of flow through the interconnections and to estimate operating conditions from 1972 to 1977. In addition, preliminary simulations have indicated that the Marston Pavilion bypass valve opening had little influence on the Holcomb Boulevard water-distribution system; analysis of this scenario will be considered further. Also, water-distribution system modeling refinements will be used to explore using climatic data along with the known booster pump operation data, as well as modeling the bypass valve opening at Marston Pavilion in a probabilistic manner.

4.0 Panel Discussions

During the 2-day meeting, panel members posed questions, provided comments and suggestions, and discussed issues related to ATSDR's water-modeling activities and the associated epidemiological study. Before the meeting, panel members also had submitted comments to ATSDR based on their review of draft technical documentation and information they received. As explained during the meeting, ATSDR would not be responding to individual premeeting comments, but would consider the issues and suggestions identified in these comments when conducting additional water-modeling activities for Hadnot Point, Holcomb Boulevard, and vicinity. This section summarizes panel members' discussion and recommendations during the meeting by individual topic, rather than in the chronological order provided in the verbatim transcripts that are contained on the CD–ROM accompanying this report. ATSDR responses and points of clarification are integrated where appropriate.

4.1 General Questions on the Epidemiological Study

ATSDR's epidemiological team provided detailed information on the study activities conducted to date and those planned for the future. Throughout the meeting, panel members asked many questions to clarify various elements of the epidemiological study. A summary of these questions and ATSDR's responses are presented below.

In regards to a table presented of monthly, model-derived exposure concentrations by gestational month, Dr. Mary Hill and other panelists suggested not presenting the numbers to three significant digits because it conveys unwarranted precision. Mr. Benjamin Harding asked how ATSDR would use a table of data that included either ranges or the empirical cumulative distribution function of values generated by a probabilistic analysis. Dr. Frank Bove said that they are still in the early stages of assessing associations rather than determining at what levels they see effects. He did not believe that the data were good enough to determine levels at which effects are seen. Nonetheless, he said, the use of less than three significant digits would not change the relative position of the cases and controls.

Regarding crude exposure estimates for people who lived in a contaminated or uncontaminated area, Dr. Hill asked if the problem was using Holcomb Boulevard as the unexposed population. Ms. Ruckart and Dr. Bove confirmed that this was the case, as they previously thought the Holcomb Boulevard system was online on or before 1968. However, that system did not come online until June 1972, and people living in the Holcomb Boulevard service area received water from the contaminated Hadnot Point system from 1968–1972 and in subsequent years during dry months when the systems were interconnected. Thus, some of the people previously characterized in the study as unexposed were actually exposed. Dr. Bove explained that ATSDR is redoing the study using not only new information on contamination but different categorizations of small for gestational age. He indicated that ATSDR will be conducting future studies using an outside reference group, such as residents at USMC Base Camp Pendleton in California.

Dr. Ann Aschengrau asked if ATSDR had residential histories for the subjects. Ms. Ruckart explained that housing information was available for the current case-control study. During interviews, ATSDR gave triggers for participants to recall their housing areas, and then cross-referenced the information with housing records and birth certificates. Dr. Aschengrau inquired whether ATSDR knew the last menstrual period date, or just had the birth date. Ms. Ruckart noted that ATSDR does not have this information; they are taking the birth date and subtracting to obtain the gestation date.

Dr. Walter Grayman asked if ATSDR was considering activities other than those occurring in the home. Ms. Ruckart indicated that survey questions inquired about other activities, and Dr. Bove added that very few cases and controls had jobs working with solvents. Mike Partain, a member of the Camp Lejeune CAP, noted that the neighborhoods on base were self-contained, and people really did not leave the base. He noted that the Post Exchange and Naval Hospital were located at Hadnot Point, so someone living at Tarawa Terrace, for example, could come in contact with contaminated drinking water at both locations.

Dr. Scott Bair followed up with a question on whether any evaluation of exposure was conducted for other areas, such as mess halls and day care centers. Dr. Bove explained that they were assuming the major part of exposures occurred in the homes, adding that not much variability was observed in showering and drinking water in the home. He also stated that people would have needed to keep diaries to determine all of the different ways of exposure.

Dr. Aschengrau expressed concern about the high levels of TCE detected at the Berkeley Manor School, and asked whether children included in the study went there. Ms. Ruckart indicated that children in the study would have been exposed in utero and up to the first year of life. Therefore, children attending school were not included in the study. Dr. Bove proposed that they could try to capture these subjects in the future health survey. Dr. Aschengrau further commented that the panel might recommend that the exposure assessment for the epidemiological study go beyond the first year of life for cancer outcomes.

Dr. Hill asked if the base population was known from 1940 to 1972. The consensus was that the numbers could potentially be estimated for how many people were served by each water-distribution system in the family housing areas, but this would not indicate how many people lived the barracks. Dr. Leonard Konikow asked if the epidemiologists wanted to be able to compare the concentrations of contaminants in delivered water to the concentrations of contaminants at the WTP. Dr. Grayman clarified that the epidemiologists needed to know exactly what was delivered to the customer. In addition, Dr. Aschengrau said that ATSDR should consider all sensitivity analyses, adding that they needed bounds of monthly estimates.

Dr. Daniel Wartenberg said it would be really helpful for the epidemiologists to see how the data changes weekly, monthly, etc., and to know the variability in the predictions. Mr. Harding indicated that the percentage of time that concentrations were above certain thresholds could be estimated, and inferences on the odds could be made from that. For example, during a 3-month period, concentrations were greater than 300 μg/L for 60 percent of the time. Dr. Rao Govindaraju noted that the model could run with data fluctuations over different time periods to provide the likelihood that a certain value would be exceeded. Dr. Hill agreed that a range of concentrations that the epidemiologists might need could be developed, such as no, medium, and high exposure. Dr. Richard Clapp added that narrow bounds of uncertainty were useful on a monthly basis.

4.2 Hadnot Point and Holcomb Boulevard Interconnection

During meeting presentations, ATSDR explained that contaminated water from the Hadnot Point water-distribution system was periodically transferred to the non-contaminated water-distribution system serving Holcomb Boulevard from 1972–1987. ATSDR explained that simple mixing models could be used for time periods when there was no indication of any interconnections: 1942–June 1972 and the months between August and March during June 1972–1987. However, from June 1972 to 1987, there were interconnections for a few days during the months of April, May, June, and July. Throughout the meeting, several panelists asked questions and requested clarification on the issue of the interconnection between the Hadnot Point and Holcomb Boulevard water-distribution systems. A summary of panelists' comments and ATSDR clarification statements are provided below.

Mr. Harding asked for clarification on whether the Wallace Creek (Marston Pavilion) valve was open at the same time that booster pump 742 (Figure 6) was used, indicating that water would be expected to flow back to Hadnot Point if the valve had been open. Mr. Maslia commented that the understanding is that the valve was open if there was insufficient flow from the booster pump. Joel Hartsoe of the Camp Lejeune Public Works Department noted that only the valve was open. Mr. Maslia explained that information about the valve being open was based on log book entries; no record was found explaining why the valve was open.

Dr. Grayman suggested charting the booster pump and the number of hours that the valve was open. He also noted that ATSDR should consider the stochasticity at the treatment plant in terms of when the booster pump was on; suggesting that a probabilistic analysis be done for the source contributions. Dr. Harding agreed, noting that the time of day was absolutely critical as well as determining whether the tank was full or empty. Mr. Maslia explained that ATSDR would not be able to complete such complex analysis because they have no time data. They do, however, have detailed concentration data associated with the January 1985 event when BTEX-contaminated finished drinking water from Hadnot Point got into the water-distribution system at Holcomb Boulevard. Data include daily records

of which wells were pumped and which were not. At this time, however, only one contaminated water-supply well (HP-651) was being operated. Several panel members suggested using these data—measurements at the WTPs and water-supply wells, pumping rates, and observed concentrations throughout the Holcomb Boulevard water-distribution system—to test the calibration of the water-distribution system model. Dr. Dougherty suggested mixing to see if there was agreement.

In terms of the amount of contamination going to the WTP from water-supply wells that are screened across and draw water from different aquifers, Dr. Bair questioned how the quantity was apportioned from the total extraction rate of a well because this would affect the mass loading for the model. Mr. Faye explained that the concentration at the water-supply well is the concentration of the mass of water in addition to the mass of contributing units, with a pumping rate assigned to each. Dr. Bair indicated that this will produce a different velocity distribution in the flow model, which will affect the concentration. Dr. Konikow concurred and suggested that ATSDR carefully consider how they represent pumpage with regard to the different aquifers in the model.

Dr. Dougherty suggested that ATSDR consider the second half of 1972 because exposure potential still existed at that time via the interconnection of Hadnot Point and Holcomb Boulevard.

Dr. Pommerenk inquired about what would be used for the historical concentrations. He noted that the groundwater model will provide monthly average concentrations, but in reality concentrations can change daily because there is fluctuation in the distribution system. In his opinion, an average was fine for Hadnot Point, but suggested not using this for the interconnection that occurred during a small time period because this would not be appropriate for the epidemiological study.

4.3 Considerations for Water-Modeling Activities

During meeting presentations, various aspects of ATSDR's water-modeling activities were discussed. ATSDR explained possible approaches to model historical concentrations, and panel members were asked for their insights and recommendations on modeling concentrations in groundwater and in the water-distribution systems. Panel members asked questions and made several recommendations. A summary of these discussions by individual topic is presented below.

Recharge

Dr. Hill inquired about whether high recharge events were considered and examined to see if they could have increased concentrations of contaminants. She noted that hurricanes might produce higher transfer of contaminants from the unsaturated to saturated zone. Dr. Konikow concurred, and added that high uncommon recharge events might not lead to dilution but to peak concentrations. He indicated that the problem with the mass loading rate and the source concentration was associated with inconsistency in the way the contaminant was released into the model. In the future model, Dr. Bair suggested that ATSDR consider spatial and temporal changes in recharge to account for droughts. Mr. Faye noted that recharge was varied on an annual basis in the Tarawa Terrace model; ATSDR did not have runoff, evapotranspiration, and similar data on a monthly basis. However, rainfall data are available, and Mr. Faye tested the sensitivity for recharge by running the model for all 528 stress periods (months). Dr. Bair suggested looking at velocities to see what would affect contaminants.

Dr. Konikow asked if the recharge rate was higher at the golf course, and if so, this higher recharge rate should be incorporated into the model.

Geological Information

Many panel members desired additional information on the construction features of the water-supply wells. Dr. Dougherty specifically inquired about whether they were sandpacked, had bentonite seals, and what the grout intervals were—or if their annuli were conduits from shallow depths to the well screens. According to Mr. Faye, almost all of the wells, if they were deep enough, were gravel- or sand-packed across the confining unit and had a seal at the ground surface. Mr. Faye indicated that the well-construction information could be added to the draft data report—provided to panel members—prior to the report being finalized.

Transmissivity

Dr. Konikow noted the many well tests and pump tests that could be used to provide estimates of transmissivity. He noted that the steady-state model presented for Hadnot Point to the expert panel assumed each aquifer is homogenous. He suggested using the aquifer-test and pump-test data to look at spatial variations in transmissivity. Mr. Faye responded by saying that the majority of the aquifer tests were in the Brewster Boulevard aquifer, which received the contamination. For the Brewster Boulevard aquifer and model layer, data are sufficient to support the investigation of the spatial variations of transmissivity, which ATSDR plans to do.

Variability in Source Term

Dr. Randall Ross asked whether more Marines passed through the base during war times, and whether this caused an increase in the use of PCE at the dry cleaners. Mr. Faye said that this was not the case based on deposition testimony provided by the owners of the ABC One-Hour dry cleaners (a dry cleaning facility located off-base near Tarawa Terrace). Mr. Faye said that there was a laundry on base also, located at Site 88, Building 25, and there is a PCE plume at Site 88 also.

Data Availability: Supplied Raw Water/Delivered Finished Water

Dr. Konikow suggested that ATSDR use monthly stress periods in the model, and said that the issue is how to reconstruct monthly withdrawals prior to 1974. Mr. Faye indicated that monthly rate could probably be apportioned to the percent of total well capacity. Tests could be run to change stress periods. Tests could be run for specified time periods for which data are available, and then water levels could be checked for a month-long period. Dr. Grayman pointed out that there is a 20-year period when only annual pumping data are available. For this situation, he suggested using population data to estimate withdrawals.

Well-Head Concentration Estimates

Dr. Hill listed three ways to deal with developing well-head estimates:

1. take measured concentrations, project back in time, and feed these values through a mixing well system,
2. use a linearization of the system as proposed by Dr. Aral, and/or
3. use a groundwater model.

Dr. Aschengrau indicated that a more accurate ranking of study subjects would not be possible with the first method mentioned by Dr. Hill. Dr. Konikow cautioned that modelers have to know the pumping history of each well and the concentration history in the well or at the well head. He suggested keeping this conceptually simple by using MODPATH to get an initial flow path and using this to get a known history for each well.

Water-Supply Well System Operation

Dr. Dougherty noted that stress apportionment should be considered, and asked about examining the record to see how the systems were operated. Mr. Faye explained that the systems were reportedly operated 12 to 16 hours per day. Once a model is selected, tests can be run for specific wells using various stress periods (e.g., 12 hours, 24 hours, and monthly). ATSDR will consider matters of both routine and exceptional operations. For instance, one concentration detected after a well was turned on for 12 hours was much lower than a concentration detected after the same system ran for 24 hours per day for 8 days.

Dr. Pommerenk emphasized the importance of knowing exactly how the systems were operated because this could result in large differences; operation details need to be worked out and incorporated into the results. He indicated that a complicating factor was that the total well capacity exceeded the demand by over 100 percent in some cases. Thus, the operator had twice the number of wells available as needed. As a result, on any given day, the system could be using a set of wells that were less contaminated or more contaminated—an issue creating a lot of uncertainty. Mr. Faye indicated that daily logs are available for active supply wells dating from January 1998 to June 2008; using this information and extrapolating back in time could reduce this uncertainty.

Dr. Grayman asked whether the wells were checked daily or if there was a particular time that they were checked to see if they were on or off. Mr. Sautner indicated that the wells were on for a complete 24-hour period. Mr. Harding cautioned that a different approach is needed to handle this issue for the groundwater versus the water-distribution system model. Dr. Pommerenk agreed, adding that not all of the wells pump discharge to the same head and that ATSDR needed to see how well operations affect how each well pumps.

Mass Computation

Panel members were presented with the purpose and methodology for the mass computation. Dr. Konikow asked whether the goal was to estimate the mass at one point in time or to estimate the initial mass, questioning how this would relate to the model input. Ms. Anderson explained that a number of steps were involved in the mass computation, including temporal considerations. Dr. Bair asked if aquifer thickness would be considered and if a uniform porosity would be used. Ms. Anderson replied that ATSDR would derive a horizontal distribution by looking at a single aquifer, then estimate and extend this process across another aquifer. ATSDR also will be looking at different porosities and clay units. In response to considering non-detects as zero, Dr. Dougherty asked if nearby (space or time) detects would be taken into consideration. Dr. Pommerenk was in agreement, noting that a non-detect set to zero could result in an underestimation. Ms. Anderson said this could be considered to refine the methodology. Two panel members inquired how ATSDR would estimate past mass loading rates, pointing out that the challenges are not the same as for Tarawa Terrace. Mr. Faye acknowledged the challenge of reconstructing this history, as ATSDR needs to quantify the contaminant mass prior to extraction by water-supply wells.

Groundwater Modeling Approach

ATSDR presented the proposed modeling approach for groundwater flow and contaminant fate and transport, as well as very preliminary results from the steady-state flow model. Dr. Hill suggested reevaluating the conceptual model because she believed there was a conceptual model problem because of the parameter values obtained from the estimation process. Dr. Govindaraju cautioned that the

parameter estimation approach still must include constraints. Dr. Konikow expressed major conceptual concerns with grouping the Brewster Boulevard geohydrologic units into one layer. He indicated that the upper clay unit has a significant effect on contaminant transport, and grouping these into one layer would smooth out all of the influence on contaminant transport. Mr. Suárez-Soto explained that the layers would be separated when going to the local model. Dr. Hill said not to lump layers to avoid dry cells, but rather to use the MODFLOW HUF (hydrologic unit flow) package to define the thickness of the layers.

Water-Distribution System Modeling Approach

ATSDR presented calibration results for Hadnot Point that assigned eight different demand categories to estimate the 24-hour demand patterns using PEST (see Section 3.7.3 in this report). Mr. Harding suggested calibrating one pattern that was used rather than eight different classifications for water demand usage. He indicated that if the exact pattern was calibrated for 5 days, then extrapolation to other times when there are no data would not be possible. Mr. Sautner noted that ATSDR assumed that demand patterns did not change much historically. Mr. Harding explained that if you took 24-hour patterns for each of the eight demand categories, then you could fit it to look at 5 days all together or to a 24-hour period. He suggested conducting the calibration using the same extrapolation procedure.

Mr. Maslia clarified that ATSDR ran PEST based on five 24-hour days, and adjusted demand patterns to yield an optimized demand. Mr. Harding suggested fitting the 24-hour pattern for each category of use, and then replicating this over 5 days because people do not behave the same way every day. Dr. Grayman suggested taking the best repeating 24-hour demand pattern to use for past or future modeling. Dr. Hill suggested considering doing a weekly repeated pattern instead of a 24-hour pattern. Mr. Maslia added that each military installation had a water-use survey done for conservation purposes. This study provides the gross amount of average water usage, including showering, filling swimming pools, etc. ATSDR derived initial values by using the data contained in this survey.

Panel members were asked if ATSDR could come up with a typical day with bounds—to indicate what exposure would be at different points in the distribution system. Specifically, the epidemiological study team needed to know whether the generation of monthly exposure data or quarterly data was possible. Dr. Konikow indicated that the ability to develop exposure data based on these time frames would rely on how well the model predicts the well-head concentrations. Mr. Harding said that the groundwater model will provide the well-head concentrations; specifically, the vertically averaged concentration on a monthly basis. Dr. Govindaraju concurred that the model would provide monthly averages that ATSDR would need to somehow fractionate or disaggregate into much smaller intervals.

Mr. Harding said the water-distribution system model had to be done on an hourly or sub-hourly basis. He said you could use the source of water function in EPANET to calculate the percentage at each node. Keep coefficients and load them however you choose with what comes out of the Holcomb Boulevard mixing model. In the Hadnot Point system, the memory in the tanks will be important if contamination is going on and off; for this case, use the superposition approach. Dr. Grayman suggested spatially treating Hadnot Point as a single unit, and that Holcomb Boulevard could possibly be considered by assuming that Berkeley Manor was homogenous. Dr. Dougherty suggested performing multiple scenarios on a sub-daily basis. Dr. Konikow indicated that, based on the planned modeling scenarios, there was no way to reproduce the observed variance in the wellhead concentration that is fed into the WTP.

Dr. Clark questioned whether degradation products had been considered, whereas Mr. Harding suggested focusing on the big picture rather than on degradation products. Mr. Harding also emphasized that understanding the pattern of water usage was important and ATSDR had to be able to set error bars. Dr. Grayman suggested looking at the patterns yielded in PEST and examining them to see if they were reasonable.

Dr. Dougherty asked about the historical sampling procedures used, noting that there could have been a loss of contamination due to volatilization. Mr. Faye indicated that a mass balance could be performed to check the concentration.

Dr. Pommerenk explained that a large treatment plant was located between the groundwater (raw water) reservoir and the water-distribution system at Hadnot Point. This station pumps into catalytic softening units, which overflow to a central pipe, then to a rectangular basin, then to gravity filters, and go to a clear well after chlorination. He indicated that he had not examined the recarbonation basin. It was put in place in the 1940s, but he did not know if it was ever operated, and if so, how often. If it was operated, it could have significantly reduced the PCE and TCE concentrations in the plant. That being said, it might be worthwhile to look at BTEX and investigate the removal from the plant and find out if the recarbonation basin ever went online.

Dr. Grayman highlighted, and others agreed, that ATSDR needed to focus on the following five areas for the water-distribution system modeling:

1. well-head concentrations,
2. well operation scenarios,
3. interconnection scenarios,
4. water-use demand scenarios, and
5. system operation scenarios (i.e., WTPs).

Calibration

Several panel members suggested that ATSDR was concentrating too much on formal calibration, and should think more about how to get a reliable, realistic model for the time periods when there are no data. Dr. Hill suggested calibrating and using cross-validation as a measure of uncertainty instead of Monte Carlo. In summary, the panelists did not agree with the calibration criterion used. Overall, the panel members agreed that calibration targets should not be pre-specified.

Airline Measurement Data

Many panelists were unclear on the purpose for including the airline (i.e., a method used to measure water levels in wells) measurement data in the technical documentation due to the large error bars. They suggested not considering or including these data in any further analyses or assigning the airline data lower weights.

4.4 Contaminant Concentration Distribution

During the meeting, ATSDR presented several maps and graphs indicating the source areas and depths of PCE, TCE, and benzene contamination. The purpose of this information was to show panelists the concentration distribution of the contaminants in groundwater. A summary of the discussion on this topic is included below.

Panelists suggested that the figures should provide more detail about the distribution of groundwater contamination associated with water depth. Specifically, Dr. Bair indicated that depth distribution would be helpful to correspond with layering in the model. For instance, does a particular sample represent contamination at a 50-ft, 20-ft, or 10-ft screen, and is it a sample across multiple aquifers? He indicated this was critical to setting up calibration and predictive models. Mr. Harding noted a strong correlation between where TCE was looked for and found, adding that the TCE contamination was detected fairly close to the supply wells. Panelists also suggested considering the well depth because contamination could be pulled from shallow to deep groundwater if one well was on and one well was off, particularly given previously discussed well-construction details. Mr. Faye noted that ATSDR was looking at contamination from shallow depths because there were many more shallow monitoring wells than deep monitoring wells. Dr. Hill commented, however, that there is no indication that the groundwater is not as polluted at depths as it is at the surface. She suggested testing how the mass of the contaminant plume retreats.

4.5 Control Theory Based Time-Series Analysis

Panel members heard a very detailed presentation on a computational method, referred to as the control theory based time-series analysis, that could potentially be used as a screening-level method for historically reconstructing contaminant concentrations in Hadnot Point and Holcomb Boulevard water-supply wells (see report Section 3.5). This method would provide an estimate of historical concentrations at contaminated water-supply wells without developing and calibrating complex numerical models for groundwater flow and contaminant fate and transport. Several panel members had questions about the control-theory analysis, which are summarized below.

Dr. Govindaraju suggested using the information obtained from this method to constrain the numerical groundwater-flow model, and let the groundwater model be used for the times when there are no data. Although Dr. Dougherty agreed that the linear modeling approach was intriguing, and suggested that it be explored in parallel for areas where the data are appropriate (e.g., pump schedule, mass loadings, contaminant sources), he said it was not appropriate for actual use in these water-modeling activities study because it has no history of application.

Dr. Pommerenk commented that it seemed the method would lump everything into something more homogenous than it is, and specifically cited three concerns: (1) you still need a pumping schedule, (2) it was unclear where the internal data parts came from, and (3) it seems to rely heavily on the time period. Dr. Aral responded to Dr. Pommerenk's concerns on using the Control Theory Based Time-Series Analysis model. He explained that an assumption was made that the landfill area was homogenous; he was not proposing to apply this to the entire region but rather to a small area for which they have monitoring data. Regarding the internal data points used with this method, these data are available for some water-supply wells at Hadnot Point and Holcomb Boulevard. Regarding the time period, the model considers a time when no contamination was present in a well and moves forward. For the backward solution, on the other hand, the method interprets the expected beginning of contamination and goes back in time (see details in Section 3.5 and Dr. Aral's presentation on the CD–ROM accompanying this report).

Dr. Dougherty was concerned that the source strength was not incorporated into this model. Dr. Aral explained that a portion of the matrix characterizes the source being observed at the monitoring well. In that manner, the matrix incorporates the concentration sources, aquifer parameters, and other factors. Dr. Hill was concerned that this was producing a system that could not be checked. Dr. Aral indicated that ideally he would have the model look at a number of observation point characteristics, and propagate an error using a computational error method that will show up in the solution. Dr. Dougherty said that the consistency between the data and the physics-driven system will provide a lot of comfort in the estimates. He also commented that taking the local-scale transport and fate models and applying them to the matrix may enable a comparison of the condensed matrix coefficients to those obtained from the linear-control system.

Dr. Aschengrau asked if the control theory had been validated against other models or data. Dr. Aral said the only validation done was the use of the Tarawa Terrace data shown in the presentation. He went on to say that they are not proposing to use this model without extensively testing it; rather, he would need to test the model repeatedly to have confidence in its outcome.

4.6 Additional Data Considerations

Panel members were asked for their guidance on how to handle the more than 150 additional UST data reports that ATSDR became aware of during March 2009; ATSDR has since obtained copies of the UST reports. For example, should separate ATSDR data reports be completed using the IRP data and UST data; should the UST dataset be used as a second set of field data for model verification purposes? In other words, if ATSDR gets to a point of confidence with model simulation, then they could see how the results compare when using the second dataset. Dr. Dougherty asked if the UST contents were known. Mr. Faye indicated some had gas, diesel fuel, heating fuel, and waste oils. Dr. Ross indicated it might be useful to break down the contaminants. Panel members discussed various uses for these additional data, but no consensus was ever reached by the panel.

In addition to discussion on the use of the UST data contained in recently obtained reports, various panel members suggested additional types of data that might be useful for ATSDR's water-modeling activities. These are summarized below by data type.

Flow Data

Dr. Bair indicated that more field work was needed. Specifically, he suggested conducting field tests to obtain tritium/helium data, which could provide flow/velocity data for calibrating the flow model. Mr. Faye pointed out that most of the contaminated water-supply wells have been destroyed. Dr. Bair commented that monitoring wells located along the flow path could be used to determine the length of the flow path at a particular distance. Dr. Konikow suggested that there was some value in age-dating to get samples, but noted that boreholes are open to multiple aquifers and thus it might be difficult or impossible to get undisturbed data. He suggested using MODPATH because it would provide a lot of insight and information at almost no computational cost. In his opinion, this was a logical step before dispersive transport modeling.

Dr. Hill suggested obtaining streamflow data if available. Mr. Faye indicated that the U.S. Geological Survey (USGS) in North Carolina has standard regression curves for estimating average conditions. Dr. Grayman suggested using PEST to get the initial recharge values and then setting bounds to more accurately estimate the amount of water entering the surface.

Trihalomethane (THM) Data

Dr. Clark suggested looking at the total THM method data because it was good at capturing VOCs. These data may have utility as an indicator for interconnections between the systems.

Tree-Ring Data

Dr. Bair noted that tree-ring data might provide surrogate information for TCE. He suggested finding a laboratory that could analyze annual growth rings to determine whether the trees contained high/low/no levels of TCE, and using this as a surrogate for time periods when no data are available.

4.7 Current Situation at Camp Lejeune

Dr. Konikow asked about the present conditions of water supplies at Camp Lejeune and the process for abandoning wells. Mr. Faye noted that the modern active water-supply wells have been distributed along Brewster Boulevard; all are located far away from contamination and sampling confirms the wells have no present contamination. Brynn Ashton of USMC Base Camp Lejeune commented that the wells were abandoned according to North Carolina laws, which does not require the casings to be removed. Dr. Dougherty noted that if these wells were abandoned by filling casings with grout, then, given previous information on well construction, they may well continue to act as vertical conduits.

5.0 Public Statements to the Panel

Prior to the meeting, Mr. Jerome Ensminger (retired USMC and member of the ATSDR CAP) and Dr. Dan Waddill (Head, Engineering Support Section, Naval Facilities Engineering Command) requested to be placed on the meeting agenda during the scheduled public comment period on Day 1. Information presented by Mr. Ensminger and Dr. Waddill is provided verbatim in the meeting transcript (specifically, Volume I of the transcript on the CD–ROM that accompanies this report) and in Appendixes C and D, respectively.

5.1 Public Statement by Mr. Jerome Ensminger Member of the Camp Lejeune Community Assistance Panel

Mr. Ensminger began his presentation by reading his personal statement to the panel (p. C2). In summary, he explained that he is a member of the ATSDR Camp Lejeune CAP and has been involved with contamination issues at the base since August 1997. He has researched thousands of base-related documents, and in his opinion, representatives from the DON and the USMC have and continue to misrepresent and withhold data that document contamination in base drinking-water supplies at Camp Lejeune.

5.1.1 Document Discussion

During his presentation, Mr. Ensminger referred to several documents he had obtained, including internal base memoranda, analytical sampling results, and other information related to base drinking water. The first document he referred to (p. C5–C6) was a letter from USEPA's Region IV office to Camp Lejeune's Environmental Quality Branch, indicating that USEPA representatives were aware of evidence of "diffuse contamination of the groundwater with unspecified organic substances" from sampling results dating back to 1983 or 1984. The letter indicated that as a result of this sampling, some of the potable wells in Hadnot Point were removed from service. USEPA indicated it was still concerned that people on base were potentially being exposed to hazardous contaminations through the water supply.

Mr. Ensminger read excerpts from another document (p. C7–C8) that contained verbatim conversations from a technical committee meeting during August 1998, with specific reference to comments made between the City Manager of Jacksonville, North Carolina, at that time (Jerry Bittner) and the Environmental Engineer at USMC Base Camp Lejeune (Bob Alexander). During this conversation, Mr. Bittner asked Mr. Alexander about the water-quality tests on the contaminated wells, and Mr. Alexander indicated that the base had minimal, if any, data prior to identifying the groundwater contamination. In Mr. Ensminger's opinion, this was a complete falsehood. The conversation continued with Mr. Bittner asking for confirmation that there was no record of the well contamination in terms of pumpage, and Mr. Alexander indicated that tracking the contamination to specific Hadnot Point wells "would be practically impossible." Following this statement, the document presented shows that Ms. Cherryl Barnett of the Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia, indicated that contamination was not discovered prior to EPA making it a requirement to test finished water for VOCs.

The next document (p. C9–C10) presented a July 1982 sampling report sent from Grainger Laboratories to USMC Base Camp Lejeune's Commanding General. In this document, a chemist from Grainger Laboratories states that there have been difficulties conducting monthly trihalomethane analyses, which he believed to result from interferences caused by high levels of chlorinated hydrocarbons. This report presented well-field sampling results, documenting a maximum TCE concentration of 1,400 μg/L and a maximum PCE concentration of 15 μg/L at Hadnot Point and a maximum PCE concentration of 104 μg/L at Tarawa Terrace. Other documents presented by Mr. Ensminger (p. C12 and C13) indicate that, dating back to as early as 1980, water-quality labs had interference when analyzing total THMs and recommended sampling for chlorinated organic compounds. One such report (p. C14) dated March 1981 included the following remark about Hadnot Point: "Water highly contaminated with other chlorinated hydrocarbons (solvents)!"

Mr. Ensminger presented a letter dated September 2, 1994, from ATSDR to the Navy Environmental Health Center's Engineering Support Department (p. C15) in which ATSDR states that the agency has had extreme difficulty obtaining documents from USMC Base Camp Lejeune that are necessary to prepare a public health assessment. Mr. Ensminger emphasized the portion of the letter that states that ATSDR made many requests to obtain necessary documents, but in most instances, inadequate responses and/or no documentation were provided to the agency.

The next document (p. C16) presented was a copy of an e-mail sent on November 16, 2000, from Kelly Dreyer, the Environmental Restoration Program Manager at Headquarters Marine Corps to Neal Paul with USMC Base Camp Lejeune's Installation Restoration Program. In this e-mail, Ms. Dreyer requests that the base provide ATSDR with information about when the Holcomb Boulevard water-distribution plant was built, and about which water-distribution system(s) provided water to people in the Midway Park, Paradise Point, Berkeley Manor, and Watkins Village housing areas.

The final document (p. C17–C18) presented was a letter dated December 9, 2005, from Howard Frumkin, Director of NCEH/ATSDR, to Lieutenant General Richard S. Kramlich, Assistant Commandant, USMC Headquarters. The letter requested information so ATSDR could resolve outstanding issues related to its water-modeling activities supporting the agency's current epidemiological study. Dr. Frumkin noted that ATSDR has had delays in receiving requested information and data related to past water-sampling results and remedial investigation reports, and requested that the Marine Corps immediately provide all documents related to base-wide drinking water.

In summary, Mr. Ensminger stated that representatives of the DON and USMC have provided ATSDR with inaccurate and incomplete data and have been untruthful to the public about the extent of base contamination. He said that the base ignored continuous warnings about contamination and recommendations for well sampling, and the base's neglectful behavior led to the drinking-water contamination at USMC Base Camp Lejeune. In his opinion, base officials knew about the contamination in the Tarawa Terrace and Hadnot Point well fields by August 1982, but made excuses instead of taking action to investigate the contamination. Mr. Ensminger said several questions need to be asked, but the main question was why it took the base more than 4 years to sample the water-supply wells. He expressed his belief that the DON requested this panel with the intention of squelching ATSDR's Hadnot Point water-modeling activities. In his opinion, these activities must continue to increase the scientific understanding of the health effects that can result from human exposure to these contaminants.

5.1.2 Discussion between Mr. Ensminger and the Panel

Mr. Harding noted that one of the charge questions to the panel was to assess the time line of the study. He asked Mr. Ensminger about his sense of stakeholder preference with regards to the time line, and whether they would prefer that the study take longer if the answers could be better. Mr. Ensminger indicated that anyone who is deeply involved would rather ATSDR take more time if it was needed to get the science right. However, he took exception if the time line had to be extended because the base did not provide documents needed by ATSDR.

Dr. Clark indicated that the total THM method was good at documenting VOC contamination, and questioned whether Mr. Ensminger had looked at more than the three samples presented. Mr. Ensminger said there were many documents, but that the labs were told to stop quantifying the chemicals detected. Specifically, Dr. Clark wondered if there were any samples over time to see the changes in TTHM samples. Mr. Ensminger had not seen too many sample results after the ones presented.

Dr. Grayman pointed out that there seemed to be a lot more data available for 1998–2008, and asked if utilities were required to hold onto 10 years of data. According to Mr. Ensminger, this was a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirement. He added that the State of North Carolina had no records for 1968–1991. He provided a link to a Web site that was created for victims: *http://www.tftptf.com*. Mr. Ensminger said the numbers of non-Hodgkin's lymphoma, leukemia, kidney cancer, bladder cancer, and other illnesses among people who formerly lived at the base "were unbelievable." Mr. Partain, another member of the Camp Lejeune CAP, added that the Web site provides a time line and contains records and documents. Mr. Partain is now working on adding information from 1990 to the present.

5.2 Public Statement by Dr. Dan Waddill Representative of the Department of the Navy

Dr. Waddill introduced himself, explaining that his group at the Naval Facilities Engineering Command (NAVFAC) Atlantic provides technical support for Navy and Marine Corps sites across the continental United States and Alaska that are being investigated and remediated. He has a background in groundwater-flow and contaminant transport modeling, and he has applied these models at many military sites. In 2008, he provided comments on ATSDR's report documenting

the agency's water-modeling activities for the Tarawa Terrace area of USMC Base Camp Lejeune. Dr. Waddill indicated that the Navy and Marine Corps completely support the effort to determine exposure concentrations at Camp Lejeune and to evaluate the potential health effects associated with exposures at Tarawa Terrace, Hadnot Point, and Holcomb Boulevard. He noted that the panel's efforts and recommendations were much appreciated, and stated that they all share a common goal—for the epidemiological study to be supported by the best available science.

To clarify his comments that will follow, Dr. Waddill defined how he would use the terms "accuracy" and "precision" in reference to model output:

1. Accuracy: the extent of agreement between model output and measured data, which would be estimated by comparing the model to the real world (e.g., assessed by comparing model-simulated concentrations of PCE to measured PCE concentrations).
2. Precision: the extent of agreement among various model runs, which would be estimated by comparing one model run to another (e.g., assessed by using sensitivity analysis).

5.2.1 Groundwater-Modeling Issues to Consider

Dr. Waddill requested that the panel members consider the following three issues associated with the groundwater-modeling efforts during their discussions: data availability, uncertainty, and model calibration.

Data Availability

Dr. Waddill referred to the question in Section 2b of the charge to the panel (Appendix A) that asks, "Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure concentrations?" He requested that the panel members evaluate a more preliminary issue, which was whether or not the modeling effort for Hadnot Point would be capable of providing reliable average concentrations on a month-by-month basis. He questioned whether the model would be able to produce these monthly concentrations with the accuracy necessary for an epidemiological study, or if this type of monthly output was a finer resolution than this modeling could produce.

Dr. Waddill explained that this issue needed to be considered because the modeling for Hadnot Point will face the same issues as Tarawa Terrace in that models must reconstruct historical concentrations back to the 1940s or 1950s because no concentration measurements for PCE, TCE, and other contaminants are available before the 1980s. He referred to the effort at Tarawa Terrace, where model output from the early 1980s back to the 1950s could not be compared to actual PCE data, resulting in approximately 30 years of unverifiable model output. Although probabilistic analysis was used at Tarawa Terrace to evaluate uncertainty based on model precision, it could not provide information on how accurately the reconstructed concentrations matched actual past exposures. Thus, because the situation for Hadnot Point is similar but much more complicated than for Tarawa Terrace, he questioned whether the uncertainty would be so large that month-to-month concentrations could not be distinguished.

Uncertainty

For Tarawa Terrace, probabilistic analysis was used by comparing model runs to each other to examine uncertainty with respect to the precision of the model output. However, Dr. Waddill noted that consideration of how the model compares to the real world was critical. In Dr. Waddill's opinion, one could not assume that the model would be more accurate for predicting concentrations in the 1960s or 1970s than the 1980s, but he would leave this up to the panel members to determine. Overall, he requested that the panel consider uncertainty with respect to model accuracy as well as model precision, and to consider how uncertainty in model accuracy can be assessed and conveyed to the model users, including the public and the epidemiologists. For example, he agreed with suggestions from the panel members noted earlier on Day 1 that presenting ranges of model-derived exposure concentrations to convey uncertainty might be more appropriate than using three significant digits.

Model Calibration

Dr. Waddill referred to the charge question in Section 3a (see Appendix A) that asks panel members: "Are there established standards or guidelines in the fate and transport modeling community for determining and applying specific calibration targets? If so, what are those standards or guidelines?" Given this approach, he asked panel members to consider how the model results should be interpreted if the calibration targets are not met. He referred to the approach used at Tarawa Terrace, where the selected calibration range included model-derived PCE concentrations that were roughly three times higher or lower than the measured concentrations. After calibration, simulation concentrations fell out of the range in some instances. He pondered whether a more general and useful approach might be to consider how the performance of the model during calibration should be assessed and conveyed to model users. In his opinion, this was important because it shed light on model accuracy, and helped users understand the uncertainty with respect to accuracy.

5.2.2 Discussion between Dr. Waddill and the Panel

In regards to Dr. Waddill supporting the suggestion to present ranges of values rather than a single number to convey uncertainty, Dr. Grayman cautioned that you had to be careful not to convey that every value within a range is equally likely to occur. Dr. Waddill agreed, and indicated that he was asking what type of recommendations the panel might suggest. Dr. Clapp said that they are looking to see the people who developed a disease on a relative scale. In other words, it was not about having to have cumulative exposure at a concentration such as 500 µg/L, but rather determining if a person was in the highly exposed or other defined exposure group. Dr. Wartenberg added that characterizing and defining exposure groups would have to do with the methods used, and indicated that this becomes more complex when grouping dates and having different categories. Dr. Hill indicated a first-order analysis, obtained using calculated average measured concentrations and groundwater withdrawals and distribution, could be used to approximate doses. Differences between such a simple analysis and results using a groundwater model are an indication of the importance of groundwater modeling.

Regarding Dr. Waddill's comment on the relationship between the "model fit" and uncertainty, Dr. Hill said that she would be suspicious if the model fit exactly, and hence, that the balance is not always easy to deal with.

Mr. Harding said it was important if the model value did not agree with the measured value, but added that ATSDR needed to look at accuracy in a much richer way because laboratory results are observations, not the "truth," and individual samples are not representative on the same time scales this study is dealing with. Dr. Waddill explained that the Navy wanted to address the best way to ascertain uncertainty because of the issues and inaccuracies associated with the sampling.

6.0 Summary of Panel Members' Recommendations and ATSDR's Responses

Prior to the end of the meeting on Day 2, each of the 13 panelists individually provided their final overall comments and recommendations to ATSDR. The verbatim transcript of the meeting contains the comments and recommendations expressed by each panelist (specifically, Volume II of the transcript on the CD–ROM). The overarching recommendations of the panel are summarized below. The panel recommendations and ATSDR's responses are grouped into six categories.

6.1 Modeling

Panel members recommended several actions for ATSDR to take with regards to the groundwater and water-distribution system modeling, including

1. use simpler, physically-based models that are data-driven for both groundwater and water-distribution system modeling;
2. use a simpler approach to groundwater transport, such as MODPATH, to determine advective transport prior to using advection-dispersion modeling;
3. use a stochastic well operation/water-supply well model for the water-distribution systems;
4. separate the Holcomb Boulevard modeling into two different analyses (that can be coupled together), with a groundwater wellhead-type of analysis and a water-distribution system analysis;
5. conduct sensitivity and uncertainty analyses (e.g., Monte Carlo analysis) to refine estimates of the model parameter values and to characterize and perhaps reduce the uncertainty from the groundwater model (i.e., predicting concentrations at the well heads) to the distribution system;
6. use simplified approaches to cross-check data interpretations and model results;
7. further explore the use of control-theory concepts for reconstructing historical concentrations at contaminated water-supply wells; and
8. convene technical groups of three to four experts periodically during the course of future water-modeling activities to provide ATSDR with more frequent technical input.

RESPONSE: ATSDR agrees in principle with panel recommendations. The water-modeling team is planning to devote significant effort to developing simplified modeling approaches and applications for the Hadnot Point and Holcomb Boulevard areas. The use of conceptually simplified modeling approaches augmented by local-grid refinement (LGR) to model selected sites of interest is most likely a prudent approach. However, ATSDR believes that a particular simulation code or model should not be selected a priori and forced to fit site conditions and characteristics. Rather, ATSDR's approach is to select or develop simulation tools based on site-specific conditions, characteristics, and requirements. Thus, the most appropriate model should be applied to characterize a system, even if it may not be the most popular or often-used model.

6.2 Calibration

Several panel members suggested that ATSDR concentrate more of its efforts on how to get a reliable, realistic model for the time periods when there are no data rather than expending time and resources on formal model calibration. Overall, the panelists did not agree with the calibration criterion ATSDR planned to use. Panel members also agreed that ATSDR should not pre-specify calibration targets. The consensus among panel members was that emphasis should be placed on more objectively estimating model parameters than on trying to closely match observed water-level or concentration data with model simulated results for model calibration.

RESPONSE: ATSDR agrees in principle with panel recommendations. The water-modeling team is planning to place emphasis on estimating key parameters, quantifying parameter sensitivity, and applying objective and automated calibration methods, such as nonlinear parameter estimation, to selected high exposure sites within the Hadnot Point and Holcomb Boulevard areas.

6.3 Epidemiological Study Needs

Panel members concurred that the epidemiological study could be accomplished. ATSDR epidemiologists strongly emphasized the need for reliable monthly concentration levels because of the small windows of vulnerability for the specific birth defects under evaluation in the case-control study (i.e., neural tube defects and oral clefts). Epidemiologists on the panel agreed, indicating that having monthly exposure estimates was the goal for the study, and that levels of uncertainty needed to be explicitly identified. Panel members concurred that the goal of the Hadnot Point system modeling should be the estimation of monthly average concentrations with associated confidence intervals. Many panel members stated that this was a feasible and attainable goal. Two water-distribution system experts on the panel concurred it was possible to calculate monthly probabilistic estimates of concentrations reaching the customers of these water systems.[11] Moreover, two panel members with expertise in epidemiology recommended that the epidemiological study extend the exposure period for childhood cancers beyond in utero and the first year of life. One panel member, an epidemiologist, recommended ATSDR consider potential exposures occurring in on-base schools within Hadnot Point and Holcomb Boulevard.

RESPONSE: ATSDR will investigate the feasibility of extending the exposure period for childhood cancers beyond the first year of life and including potential on-base exposures at school.

[11]Subsequent to receiving panel members' comments on the draft version of this report, one panel member sent ATSDR a letter dated October 22, 2009, stating that he did not concur with the statement that it would be possible to obtain monthly concentration estimates without further qualification.

6.4 Interconnection between Hadnot Point and Holcomb Boulevard

Panel members agreed that it would be difficult to model the time period when the Hadnot Point and Holcomb Boulevard systems were interconnected (i.e., 4-month periods during dry spring and summer months and a 2-week period in January 1985), but they were optimistic that ATSDR could provide estimates for this period. Specific recommendations suggested using a detailed water-distribution system model to conduct extended period simulation scenarios over several months depending on what was observed in the tanks for the water-distribution system.

RESPONSE: ATSDR agrees in principle with panel recommendations. The water-modeling team is planning to devote additional effort to developing an understanding of water-supply well on/off cycling operations based on discussions with Camp Lejeune water-utility staff and available daily and monthly operational records.

6.5 Additional Data Needs

The panelists had several suggestions for additional data needs, including tracer test results; records of cores, clays, and confining layers; water-level data; well construction and abandonment details; tritium/helium data; information on how pumps turn on and off; and specifics on how the hydrogeologic systems react. Panel members acknowledged that important information gaps exist and that cooperative efforts between ATSDR, USMC, and DON should continue to ensure that ATSDR has all of the data and documentation necessary to accurately and efficiently complete its water-modeling activities and epidemiological study.

RESPONSE: ATSDR agrees with panel members that better field characterization and details should be added to conceptual models to improve understanding of both hydraulics and transport at selected sites where potential exposure was high. ATSDR completed all data discovery activities, in cooperation with Camp Lejeune staff, by September 2009.

6.6 Time Line of Project

Panel members concurred that completing the historical reconstruction modeling tasks for Hadnot Point, Holcomb Boulevard, and vicinity by December 2009 was unrealistic. Panelists agreed that at least a year or longer would be required to model the groundwater and water-distribution systems, analyze the results, and provide the necessary concentration estimates to the epidemiological study team.

RESPONSE: ATSDR agrees with the panel recommendation that additional time, beyond December 2009, is required to model groundwater and water-distribution systems, analyze results, and provide the necessary concentration estimates to the epidemiological study team. The ATSDR water-modeling team believes that, if given the necessary budget in a timely manner, successful completion of these activities requires an extension of the project through the end of September 2011.

7.0 Acknowledgments

ATSDR would like to acknowledge the assistance and contributions of Dr. Robert M. Clark, Environmental Engineer and Public Health Consultant, for his efforts in chairing the expert panel. Through his efforts, ATSDR has received valuable comments and recommendations from panel members that will assist the agency in focusing future efforts and resources in completing its water-modeling analyses.

ATSDR would like to acknowledge Elizabeth Bertelsen of Eastern Research Group, Inc., who assisted with meeting coordination, logistics, and preparation of the draft text of this report.

ATSDR also would like to acknowledge Caryl J. Wipperfurth and Kimberly A. Waltenbaugh, of the U.S. Geological Survey, Enterprise Publishing Network, who assisted with preparation of text, illustrations, and electronic media.

8.0 References

Maslia ML, editor, 2005, Expert Peer Review Panel Evaluating ATSDR's Water-Modeling Activities in Support of the Current Study of Childhood Birth Defects and Cancer at U.S. Marine Corps Base Camp Lejeune, North Carolina—Analyses of Groundwater Resources and Present-Day (2004) Water-Distribution Systems, March 28–29, 2005: *Prepared by* Eastern Research Group, Inc., Atlanta, GA; *Prepared for* Agency for Toxic Substances and Disease Registry, Atlanta, GA; 31 p., 4 app. Available at *http://www.atsdr.cdc.gov/sites/lejeune/watermodeling.html*. Accessed 10 November 2009.

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Appendixes A–F

Appendix A

Agenda

Day 1—April 29, 2009

7:45 Check in at Visitors Center, Building 162, group escort to Building 106

8:15 Housekeeping Rules: *Morris L. Maslia*

8:30 Opening Remarks and Introduction of Chair: *Tom Sinks, Deputy Director, NCEH/ATSDR*

8:45 Opening Statement and Presentation of Charge: *Panel Chair, Dr. Robert M. Clark, Environmental Engineering and Public Health Consultant*

Introduction of Panel Members, Affiliations, and Related Experiences

9:15 Introduction of Camp Lejeune Epidemiological Study Team: *Frank Bove*
Introduction of Water Modeling Team: *Morris L. Maslia*
Introduction of Stakeholders: *Frank Bove and Morris L. Maslia*

9:30 Summary of Current Health Study: *Frank Bove and Perri Ruckart*
Use of Water-Modeling Results in the Epidemiological Study: *Panel Members, Frank Bove, and Perri Ruckart*

10:15 **Break**

10:30 Summary of Water-Modeling Activities: *Morris L. Maslia*
(a) Tarawa Terrace Expert Panel Recommendations
(b) Tarawa Terrace Water-Modeling Results
(c) Hadnot Point and Holcomb Boulevard Activities and Analyses

10:45 Hadnot Point/Holcomb Boulevard Presentations and Panel Discussion:

Data Analyses—Groundwater
(a) Data summary and availability: *Robert Faye*
(b) Well capacity and use history: *Jason Sautner*
(c) Mass computations: *Barbara Anderson*

12:30 **Lunch**: Cafeteria in Building 106

1:30 Strategies for Reconstructing Concentrations: Presentations and Panel Discussion
(a) Screening-Level Method: *Dr. Mustafa Aral, Ga. Tech*
(b) Numerical Methods: *René Suárez-Soto*

3:15 **Break**

3:30 Strategies for Reconstructing Concentrations: Panel Discussion—continued

4:00 Panel Chair Accepts Statements and Questions from Public[12]
(Repeat Statement of Purpose of Panel): *Dr. Robert M. Clark*
Representative of Camp Lejeune Community Assistance Panel (CAP): *Jerome Ensminger*
Representative of Department of Navy: *Dr. Dan Waddill*

6:00 **Adjourn**: Escort to Visitors Center for Shuttle to Hotel

[12]The panel chair will advise public attendees of the ground rules and request questioners to supply their names and affiliations. All questions will be addressed to the panel chair, only. The panel chair will solicit responses, as appropriate, from panel members.

Day 2—April 30, 2009

7:45 Check in at Visitors Center, Building 162, group escort to Building 106

8:15 Housekeeping Rules: *Morris L. Maslia*

8:30 Re-Introduction of Panel and Summary of Day 1 Issues and Discussion:
Panel Chair, Dr. Robert M. Clark

8:45 Water-Distribution System Modeling: *Jason Sautner*
(a) Review and Overview of models for Hadnot Point and Holcomb Boulevard
(b) Interconnection of Hadnot Point and Holcomb Boulevard systems

9:15 Panel Discussion: **Water-Distribution System Modeling**

10:15 **Break**

10:30 Panel Discussion: **Water-Distribution System Modeling**

11:30 **Lunch**: Cafeteria in Building 106

12:30 Data Discovery—Additional Information and Data: *Morris L. Maslia and Frank Bove*

1:00 Panel Discussion: **Incorporating and Using Additional Information and Data**

2:15 **Break**

2:30 Chair Solicits Response to Charge from Each Panel Member: *Panel Chair and Members*

3:30 **Adjourn**: Escort to Visitors Center for Shuttle to MARTA Station

Charge to the Panel

Given the state of the science for reconstructing historical levels of contaminants in drinking water for the purpose of estimating human exposures, do the methods used and proposed by ATSDR provide an adequate level of accuracy and precision?

To address this charge, ATSDR is requesting the expert panel's opinion with respect to the following questions. The agency encourages all opinions and views and is seeking oral and written recommendations from the panel. Thus, ATSDR is seeking a majority opinion with opposing views.

1. Based on information provided by ATSDR to the panel, are there modifications or changes that ATSDR should consider making in its approach to quantifying historical concentrations associated with:

   a. Data analysis?

   b. Groundwater flow and contaminant fate and transport?

   c. Distribution of drinking water?

   If, in the panel's majority opinion, ATSDR should consider changes in its approach, what specific changes does the panel suggest?

2. ATSDR has provided panel members with summaries of information, data, and preliminary analyses that will be used for reconstructing historical contaminant concentrations at Hadnot Point, Holcomb Boulevard, and vicinity.

   a. What data analysis and modeling complexities do panel members anticipate and what are their concerns?

   b. Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations?

3. ATSDR established a calibration target of ±½ order of magnitude for comparing measured and simulated water-quality data for the Tarawa Terrace contaminant fate and transport model.

   a. Are there established standards or guidelines in the fate and transport modeling community for determining and applying specific calibration targets? If so, what are those standards or guidelines?

   b. If ATSDR should establish different calibration targets for Hadnot Point, Holcomb Boulevard, and vicinity (compared to targets used for the Tarawa Terrace model), what should the calibration targets be?

   If, in the panel's majority opinion, ATSDR should consider changing its calibration target strategy for the Hadnot Point, Holcomb Boulevard, and vicinity contaminant fate and transport model, what specific changes does the panel suggest?

4. ATSDR has been provided with information that Hadnot Point drinking water (contaminated) was periodically transferred to the Holcomb Boulevard water-distribution system (non-contaminated drinking water) during the period 1972–1987 (typically for a few hours during April, May, and/or June). This may require the use of a water-distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.

   a. Because the water transfers occurred intermittently, which water-distribution system modeling approach do panel members recommend as the most sensible and reliable for estimating monthly mean historical concentrations (e.g., simple mixing or an all-pipes model)?

   b. Because continuous descriptions of the date and duration of the water transfers are not available, do panel members recommend simulating the spatial distribution of historical drinking water concentrations solely for a "typical" month (e.g., June) during these years?
   c. Given the intermittent supply of contaminated Hadnot Point water to the Holcomb Boulevard water-distribution system, what simulation scenarios do panel members recommend be developed to provide exposure concentrations for use by the epidemiological study?

5. ATSDR has set a target date of December 2009 for completing historical reconstruction modeling tasks for Hadnot Point, Holcomb Boulevard, and vicinity. If, in the panel's majority opinion, ATSDR should modify the project tasks and schedule, what specific activities does the panel suggest ATSDR modify and how should the project schedule be modified?

Scope of the Expert Panel

The scope of the expert panel at this stage of the project for the Hadnot Point and Holcomb Boulevard areas of the base is expected to encompass the following:

1. Assess the appropriateness of ATSDR's approach to provide results needed to address the following issues:
   a. Arrival time of contaminant-specific compounds at public-supply wells
   b. Spatial and temporal distribution of contaminant-specific compounds by study subject location
2. Review the groundwater flow component of the project:
   a. Hydrogeologic data analyses and conceptual framework development
   b. Groundwater-flow model development and calibration
   c. Appropriateness of expanse, coverage, and detail of groundwater flow model
3. Review the water-quality and contaminant fate and transport component of the project:
   a. Water-quality data and analytical methods of analysis
   b. Analysis of mass computations
   c. Fate properties of contaminants
   d. Approaches for simulating contaminant fate and transport
4. Review the water-distribution system component of the project:
   a. Review of Hadnot Point and Holcomb Boulevard water-distribution systems
   b. Review and discuss scenarios to simulate transfer of contaminated water from Hadnot Point to uncontaminated Holcomb Boulevard water-distribution system
5. Review topics dealing with sensitivity, uncertainty, and variability of model input and output parameters.
6. Review topics dealing with model calibration issues.

Appendix B

Panel Members

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Appendix C

Public Statement by Camp Lejeune Community Assistance Panel Member Jerome M. Ensminger[13]

[13] Some of the documents in this appendix include highlighted yelllow text, which was on the document received from Mr. Ensminger. ATSDR made no changes to these documents; they were included in this appendix exactly as presented to the expert panel during the meeting.

STATEMENT OF JEROME M. ENSMINGER

Good Morning. My name is Jerry Ensminger, I am a member of the ATSDR Camp Lejeune Community Assistance Panel (CAP) and I have been involved in this incident since August 1997. Over these past 12 years, I have viewed thousands of documents related to this situation and what I have discovered is both disheartening and disgusting. Department of the Navy / United States Marine Corps officials and representatives have in the past and continue right up to the present to misrepresent and deny the facts. They have done this by making false and misleading statements, providing incomplete or false data, and by withholding key data that is critical to finding the truth. I don't expect any of you to take my word as proof of the serious allegations I am making against these supposed honorable government entities. That is why I have provided all of you with some of the actual historical documents so you can witness the deception with your own eyes.

DISCUSS DOCUMENTS

These are but a few examples of the misinformation, disinformation, half-truths, and out right lies that have been told by representatives of the DoN/USMC. There are many, many more. They have provided inaccurate data to the ATSDR, they have misrepresented the levels and the extent of the contamination to the media and the public at large. They have, (pause) and continue to misrepresent their negligent behavior which

created the conditions that led to the drinking water contamination aboard Camp Lejeune. In a recent interview with Dan Rather, a USMC spokesman made the following statements. "It was not until nine…late 1984...early 1985 that is was discovered that it (the contamination) was discovered is was actually in the wells." Responding to another question from Mr. Rather, the USMC spokesman stated "Yes sir. They were…the base…was…trying to determine the source. And as soon as they discovered the source of the chemicals was the well, that well was shut down." The sole source for drinking water at Camp Lejeune are deep ground water wells. Exactly where did the authorities at Camp Lejeune think this contamination was emanating from? If it wasn't coming from the supply wells, perhaps they had some rogue water treatment plant operators who were dumping these chemicals into the water at the distribution plants. The truth is that base officials knew by August 1982 that the well fields for Tarawa Terrace and Hadnot point were the source of the contamination aboard the base's water supply system. Instead of decisive action, excuses were made….the base supervisory chemist offered a suggestion that some of the contamination could be coming from asbestos coated pipes in the systems.

Thankfully, Mr. Maslia of the ATSDR determined from DoN/USMC records that the only water distribution system aboard Camp Lejeune with any A/C coated pipes were raw water lines in the Holcomb Blvd. system. The only instances where any contamination was discovered in that system was when base operators were opening an isolation valve which interconnected the Holcomb and Hadnot Point systems. There are some very pertinent questions which need to be asked here. Why didn't DoN/USMC officials

research the construction materials of the contaminated systems back in the early 1980s? The main question would be why did it take more that four years to sample the supply wells? In fact, that question has been asked multiple times and no one can get a straight answer from the DoN/USMC.

It is my understanding that this expert panel was requested by the Department of the Navy. It is my opinion that they are hoping that this forum will "kill" the Hadnot Point water system modeling. In fact, I believe they would like nothing more! If science is ever going to have a better understanding of the effects these chemicals have on human beings, it is imperative that this effort continue. If the victims of this tragedy are ever going to fully understand what they were exposed to, this water modeling effort must be seen through to its completion.

Thank You

J. Lew 24-Feb Rec.

E. Betz

T-6241/7

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV

345 COURTLAND STREET
ATLANTA, GEORGIA 30365

FEB 3 1986

REF: 4WD-ER

Commander
Atlantic Division
Naval Facilities Engineering Command
Norfolk, Virginia 23511- 6287

Attention: J. R. Bailey, P.E.
Environmental Quality Branch

Dear Sir:

On November 1, 1985, Messrs. Mathis and Holdaway of this Agency met with Facilities Engineering Staff at MCB Camp Le Jeune to review activities and progress in assessment of past waste disposal practices through the NACIP program. During the course of discussion, the subject of ground water quality, and particularly the quality of the water obtained from wells in the Hadnot Point Area of Camp Le Jeune, was reviewed at some length.

Both Messrs. Holdaway and Mathis became aware that there was evidence, from sampling as early as 1983 or 1984, of diffuse contamination of the ground water with unspecified organic substances, and that as a result of detection of unspecified volatile organic compounds in raw potable water samples certain potable wells at Hadnot Point were taken out of service. In consideration of the fact that the major portion of the resident population of Camp Le Jeune, is dependent on the Hadnot Point well field as its potable water supply, the parties in the meeting agreed that any potential contamination of this resource should be investigated as expeditiously as practical. It was also established that there was no contamination detected in treated potable water distributed at Camp Le Jeune, however the extent and sensitivity of analytic procedures for specific organic substances was not fully discussed.

Mr. Mathis suggested it would be desirable to analyze ground water samples from the monitoring wells involved in the NACIP confirmation studies for the 129 priority pollutants (CFR261 Appendix 8), and that the same analysis should be performed on raw water from all potable wells to insure that there was no contamination of the Camp Le Jeune water supply. When EPA informally requested a copy of the analytical results from monitoring wells and potable wells, we were advised that these data were still in raw form and under review.

If these data are now available, please furnish us a copy. If these data have not been published yet, we would appreciate a brief description of what substances were analyzed, what substances were detected, and when the data will be available.

CLW

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This Agency is concerned that a potential for human exposure to hazardous substances and hazardous wastes via the Camp Le Jeune water supply may exist due to the presence of such materials in ground water in the general vicinity of the potable well field. The existance of such a potential exposure would warrent consideration of this area for inclusion on the National Priority List, with an attendant increase in the expediency of investigation and remediation.

We appreciate your assistance in obtaining these data in order that this potentially significant problem may be addressed.

If you have any questions, please do not hesitate to contact me at (404) 347-3776 or FTS 257-3776.

Sincerely,

Arthur G. Linton

Arthur G. Linton, P.E.
Regional Federal Facilities Coordinator
Environmental Assessment Branch
Office of Policy and Management

cc: Commander, MCS Camp Le Jeune
Lee Herwig
Paul Hubbell, Navy Department, Washington, DC

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Excerpt CERCLA 47

right now, the standard set for lead, both federal and within the state,is 50 parts per million. If we determine that ground water, shallow ground water, in the Hadnot Point area is below 50 then it's suitable as a public drinking supply. There's no need to treat for it. There's a fairly long list of chemical compounds in which applicable standards are available. If they're not, then we jump into very much of a gray area.

Let me back up to this. An applicable standard would be what I described before as an MCL, a maximum containment level. That's mandated by law. For public drinking water supply, it cannot be higher than this MCL. Certainly, we have federal and within the administrative code for the state, those numbers are specified. When we leave those MCLs and we get into these grey areas then we get into applicabl or, excuse me, we have relevant or appropriate. Now, how we determine what is relevant and what is appropriate becomes a negotiating position. We have to go into what I described earlier, what would be the expected human response to certain levels of contaminants. There' a lot of research available in those areas and we would go through it. There are some theoretical approaches on how to do it and there are the other standards that I'll go through in a bit. We, certainly, hav primary drinking water standards, which are like federal MCLs and those can apply. We have MCLs, as I mentioned, those are specific numbers for a lot of these volatile compounds which is what we're really dealing with here, health risk, a lot. From the federal level, they have MCLGs, MCL goals. This is your theory, this is your goal that you have to attain. Because a number of these compounds are possible and/or probable human carcinogens, the goals are typically zero. It's best not to have any in the water.

BITTNER: You talk about the future health risk and assessments going to the past. I take it all the wells go to a common treatment plant?

ALEXANDER: Yes.

BITTNER: What kind of tests were you getting when you were running those contaminated wells in terms of water quality? I imagine it would be pretty much diluted but you were still probably getting some readings if you ever took a scan.

ALEXANDER: We had very little, if any data, before we realized our ground water was contaminated.

BITTNER: So there's no record of it in terms of what you were pumping.

ALEXANDER: We had some tests--like at the Tarawa Terrace area--before we realized that ABC Cleaners was polluting our wells there. We had some tests and ended up with some measurable concentrations. But they were almost at the detectable level. When you're taking out of the Hadnot Point area 35 wells that had been servicing that system, probably a well would only run for about two days and it would only be about five or six wells running, so we had a rotating cycle of operatic on those wells. It would be practically impossible to say what wells contributed what compounds on any given day. You'd have to backtrack from the residence time in the reservoir and all that to see what wells were going two days ago.

BITTNER: And, basically, Bob, there's no record of that.

ALEXANDER: It would be practially impossible to track that down.

BARNETT: There were no requirements, you know, the requirements to test your finished water for VOCs is a new requirement. It's a new EPA drinking water requirement, so there was no prior testing program before. It was just purely in the course of this investigation that we discovered that problem to begin with and since that time they've been monitoring the finished water effluents, but it was never a requirement.

GREGORY: We were discussing the MCL goals. Once again, for a lot of the compounds, we're having to deal with zero. Current analytical technology detection limits are one or slightly less than one, so, again, from a legal point of view, nobody could verify that at zero. You can't see zero, you can only see one or so. The goals are somethir that we have to strive for. If the technology prevents us from seeing that low, then we get, once again, into these relevant or appropriate. So that would be specified. To go one step past that, we get into what's called ambient water quality criteria, which are very research oriented. What they are they are numbers that if you were to drink contaminated water and to consume contaminated organisms from that water, you get certain levels of ingestion. What sort of risk is associated with that? That's what these ten to the minus fifth. This particular number is one extra case of cancer per one hundred thousand in population. So, at that point in time, we start having to deal with risk levels. These are just potential risks based on response of laboratory animals. Most of the research in that has been fairly conservative, so that if you see a number there it's not realistic at all, it's very conservative. It's a safety factor built in. So we get down to here and we get into the point of having to determine on a project by project basis what's an acceptable level of risk. Actually, the number that is used quite a bit is ten to the minus six

0121

GRAINGER LABORATORIES

INCORPORATED
ANALYTICAL AND CONSULTING CHEMISTS
709 West Johnson Street • Raleigh, North Carolina 27603
(919) 828-3360

ANALYTICAL LABORATORY
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Fuels
Textiles
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Hazardous Waste

CONSULTATION
Metallurgical Services
Pollution Abatement
Process Development
Quality Control
Methods Development
Special Investigation
Pesticides
RCRA

August 10, 1982
82-4471

Commanding General
Marine Corps Base
Camp Lejeune, N.C. 28542

Attention: AC/S Facilities

Subject: Analyses of samples 206 and 207 from site coded "TT" and samples 208 and 209 from site coded "HP". Samples received July 29, 1982.

Discussion:

Previously all samples from site TT and HP presented difficulties in performing the monthly Trihalomethane analyses. Interferences which were thought to be chlorinated hydrocarbons hindered the quantitation of certain Trihalomethanes. These appeared to be at high levels and hence more important from a health standpoint than the total Trihalomethane content. For these reasons we called the situation to the attention of Camp Lejuene personnel.

Results:

The identity of the contaminant in the well field represented by samples 206 and 207 was suspected to be Tetrachloroethylene. This was confirmed by two analytical techniques and the results were 76 µg/l and 82 µg/l for samples 206 and 207 respectively.. Sample 86 from May 27, 1982 was reanalyzed as a part of our study. Sample 86 was from site TT and contained 80 µg/l tetrachloroethylene.

Samples 208 and 209 were also analyzed by the same analytical techniques. The magnitude of the contamination was not as great as previously observed from this same sampling point. Upon reanalyzing sample 120 from site HP May 27, 1982 , Trichloroethylene was identified and quantitated at 1400 µg/l. A lesser amount of Tetrachloroethylene was confirmed at 15 µg/l. Samples 208 and 209 contained 19 µg/l and 21 µg/l Trichloroethylene respectively; Tetrachloroethylene was not detected.

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Camp Lejuene
GLI 82-4471
August 10, 1982
Page 2

Prior to this report, the samples from July 28, 1982 from site HP were analyzed. Traces of both solvents were found in this set. Though not quantitated, the level of Trichloroethylene seems to be in the range of that which was found in samples 208 and 209. The sample which showed the most contamination relative to the others was 205. Also sample 168 from site TT on July 28, 1982 was analyzed and shown to contain 104 µg/l Tetrachloroethylene.

Conclusion:

Tetrachloroethylene was identified as the contaminant in the well field coded "TT". Its concentration seems relatively stable over the period in which it has been examined. It was confirmed that the well field coded "HP" has shown contamination by Trichloroethylene and Tetrachloroethylene. These levels have been variable over the per studied and are now at significantly lower levels than when first encountered. The following table summarizes the findings:

Sample	Date Taken	Site Code	Tri chloroethylene	Tetra-chloroethylene
206	7-27-82	TT	-	76
207	7-27-82	TT	-	82
86	5-27-82	TT	-	80
168	7-28-82	TT	-	104
208	7-27-82	HP	19	<1
209	7-27-82	HP	21	<1
120	5-27-82	HP	1400	15
205	7-28-82	HP	No Data	1.0

Bruce A. Babson

Bruce A. Babson
Chemist

BAB/ab
Customer #92400

CLW

0000000593

NORTH CAROLINA DEPARTMENT OF HUMAN RESOURCES
DIVISION OF HEALTH SERVICES
OCCUPATIONAL HEALTH LABORATORY

COMPANY:Camp Lejeune Water System
ADDRESS:Camp Lejeune, Jacksonville, N.C.
SERVICE REQUESTED:VOLATILE ORGANIC ANALYSIS
SAMPLE TAKEN ON:1/31/85
SAMPLE TAKEN BY:Betsy Betz
SUBMITTED TO LABORATORY:2/1/85
SUBMITTED BY:Betsy Betz

DATE OF ANALYSIS:2/1-4/85
ANALYSED BY:John L. NeaL

DATE REPORTED:2/4/85

RESULTS IN PPB (ug/liter)

LOCATION	DICHLOROETHYLENE	TRICHLOROETHYLENE
Bldg 20	321.3	900.0
Bldg 670 Bottom	7.4	24.1
MOQ 2212 Cold Water	249.4	724.6
Bldg 670 Top	7.6	26.8
MOQ 2212 Hot Water	201.2	612.9
Bldg 670 Middle	7.8	25.8
Tank SLCH 4004	107.5	318.3
Hydrant MOQ 2204	307.6	839.7
Hydrant Elev. Tank S-830	340.0	849.0
Tank S-2323	159.0	407.1
BM 5677	368.7	981.3
BM 5531	335.0	905.5
Bldg PP 2600	332.4	890.9
Bldg 5400	406.6	1,148.4

COMMENTS:
Also identified in all samples were chloroform, dichloromethane, and two (2) unidentified peaks possibly dibromomethane and bromoform. Total Trihalomethanes <<100.0 PPB.

REPORTED BY: John L. Neal

cc. Charles Rundgren, Water Supply Branch
Mike Bell, ERO
Fred Hill, ERO
Environmental Epidemiology

CLW
0000005371

0045
NAVY

TTHM SURVEILLANCE REPORT FORM

Installation CAMP LEJEUNE – HADNOT POINT

Date Collected 18 DEC 80 PM

Source	Sample Number	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	ug/L TTHM
WTP	N 111	20.0	?	6.2	1.0	27 +
NH-1	112	18.7	?	7.0	1.2	25 +
1202	113	19.3	?	6.8	1.1	27 +
65	114	19.9	?	6.4	1.0	27 +
FC-530	115	19.8	?	7.3	1.2	28 +
Reference OBS						
True						

Date Received 29 DEC 80

Date Analyzed 8 JAN 81

Remarks: 22

HEAVY ORGANIC INTERFERENCE AT $CHCl_2Br$.

YOU NEED TO ANALYZE FOR CHLORINATED ORGANICS BY GC/MS. William C Neal Jr

WILLIAM C. NEAL, JR.
Chief, Laboratory Services

USAEHA-S Form 7
20 Feb 80

CLW

0000000438

0050

TTHM SURVEILLANCE REPORT FORM

Installation CAMP LA JEUNE - HADNOT PT

Date Collected 29 JAN 81 PM

HEAVY INTERFERENCE

Source	Sample Number	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	ug/L TTHM
WTP	161	22.7	?	6.2	0.9	30 +
NH-1	162	27.2	?	6.3	0.8	34+
1202	163	23.8	?	6.6	0.9	31+
65	164	24.3	?	6.8	0.9	32+
FC-530	165	27.5	?	7.2	1.0	36+
Reference OBS						
True						

Dichlorobromomethane

Date Received 30 JAN 81

Date Analyzed 9 FEB 81

Remarks: YOU NEED TO ANALYZE FOR CHLORINATED ORGANICS BY GC/MS.

William C. Neal Jr.
WILLIAM C. NEAL, JR.
Chief, Laboratory Servic CLW-

0000000441

USAEHA-S Form 7
20 Feb 80

0052

TTHM SURVEILLANCE REPORT FORM

Installation CAMP LA JEUNE HADNOT POINT

Date Collected 26 FEB 81 PM

AVE 63

Source	Sample Number	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	µg/L TTHM
WTP	181	48.6	9.6	5.4	1.7	65
NH-1	182	54.5	13.8	5.5	0.2	74
1202	183	46.6	10.6	4.2	0.1	62
65	184	45.5	9.4	5.0	0.1	60
FC-530	185	43.6	8.5	4.2	0.1	56
Reference OBS						
True						

Date Received 9 MAR 81

Date Analyzed 9 MAR 81

Remarks: WATER HIGHLY CONTAMINATED WITH OTHER CHLORINATED HYDROCARBONS (SOLVENTS)!

William C. Neal Jr

WILLIAM C. NEAL, JR.
Chief, Laboratory Services

USAEHA-S Form 7
20 Feb 80

CLW

0000000443

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Agency for Toxic Substance
and Disease Registry
Atlanta GA 30333

call LANTDIV (Response planned?)
- call Yvonne Walker
(for copy of Aug 16, 94 - which generated this letter)
- Need "list of Documents" not generated "bill of complaint"

September 2, 1994

Ms. Yvonne P. Walker, CIH
Engineering Support Department
Navy Environmental Health Center
2510 Walmer Avenue
Norfolk, VA 23513-2617

Yvonne
why NAVFAC unhelpful : not us?
Carol Hassun
what's up?

Dear Ms. Walker:

I am responding to a letter received from Captain W.P. Thomas dated August 16, 1994 requesting a list of documents which ATSDR needs to conduct the public health assessment on Marine Corps Base (MCB) Camp Lejeune, North Carolina.

ATSDR identifies and obtains documents needed for evaluation to develop the public health assessment by discussing the public health issues with the installation and having them send us documents where the information can be found. As you are aware, we have had much difficultly getting the needed documents from MCB Camp Lejeune. We have sent MCB Camp Lejeune several requests for information and, in most cases, the responses were inadequate and no supporting documentation was forwarded. For example, ATSDR does not have any of the Remedial Investigation (RI) documents for this site nor do we have a copy of the administrative record index to help us identify which documents would be useful in our evaluation. The situation at MCB Camp Lejeune is also somewhat complicated in that several of our public health questions could not be answered with information from the RI reports (e.g., lead in drinking water).

need LANTDIV support
1 - never requested

no validation

The initial release of the MCB Camp Lejeune public health assessment is currently being prepared for the printer and will be released in the near future. For an ATSDR public health assessment to be useful, it is important that all pertinent information be provided for evaluation. The public health assessment lists the information ATSDR had available for evaluation for inclusion in the document. After the base has had an opportunity to read the MCB Camp Lejeune report, we must rely on the base personnel to identify and provide the additional source documentation as appropriate. We would appreciate your efforts to assure that this occurs.

Sincerely yours,

Carol H. Aloisio

Carol H. Aloisio
Office of Assistant Administrator

FF Coordinator
- Bruce Jackson

Knee Jerk

Mark Bagley's
- Carol Aloisio

CLW

0000000...

Raines GS12 Rick H

From: Paul GS13 Neal N
Sent: Thursday, November 16, 2000 9:41 AM
To: Cone GM14 Frederick E
Cc: Brewer GS14 Scott A; Raines GS12 Rick H; Jungreis Capt Jeremy N
Subject: Water Distribution Systems at Camp Lejeune

Fred,
See CMC HQ's request. Please let me know when you can meet on this.

-----Original Message-----
From: Dreyer GS13 Kelly A
Sent: Thursday, November 16, 2000 9:40 AM
To: Paul GS13 Neal N
Cc: Sakai GM14 Craig K; Raines GS12 Rick H
Subject: Water Distribution Systems at Camp Lejeune

Neal -

There seems to be a little confusion regarding when each of the water distribution systems at Camp Lejeune were installed and the timeframe and area each of them served. It's important to set the record straight.

ATSDR published a report in 1998 which assumes that the Holcolmb Blvd water distribution plant has always provided water to the Midway Park, Paradise Point, Berkeley Manor, and Watkins Village housing areas. I don't think the Holcomb Blvd Plant was even built until 1972 which makes this assumption incorrect. We are also receiving several calls from concerned citizens wanting to know where their water came from.

Can you please work with Facilities to compose a memo from Camp Lejeune to ATSDR with a copy to CMC and NEHC that contains the following information:

(1) All water Distribution systems
(2) When each water distribution system was built
- (a) which wells are connected to which water distribution system
- (b) which wells were contaminated (when and what were the levels)
- (c) Which wells were closed

(3) What areas each water distribution provided water to (housing, administrative, etc.)
- (a) the number of housing units in each housing area
- (b) Bldg numbers for Administrative buildings

(4) The timeframe each water distribution provided water to the specific area
(5) Any other pertinent information about a distribution system (e.g. Holcomb blvd was shut down and connected to the Hadnot Point system for 9 days),
WHAT WELLS SHUT DOWN ? THEN RE-PUT ON LINE

If possible, an easy to read table would be a great format to present the information in. I'd like to have the memo signed out by 1 Dec 00 at the latest. Please let me know if you need clarificaiton or are not able to meet the deadline. I really appreciate your assistance. It's important to get this information to ATSDR so they can prepare an accurate report and also update previous studies that may be incorrect.

VR,
Kelly Dreyer
Environmental Restoration Program Manager
HQ Marine Corps
DSN 225-8302, ext 3329
COM (703) 695-8302, ext 3329
dreyerka@hqmc.usmc.mil

- DOES SHE WANT DIST. SYS' NOT INCLUDED IN STUDY / TIME FRAME

CLW

0000003243

DO WE NEED 3rd PARTY REVIEW

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service
Agency for Toxic Substances
and Disease Registry

DEC 09 2005

Lieutenant General Richard S. Kramlich
Deputy Commandant of Installations and Logistics
Department of the Navy
Headquarters, United States Marine Corps (Code LFL)
2 Navy Annex
Washington, D.C. 20380-1775

Dear Lt. General Kramlich:

The Agency for Toxic Substances and Disease Registry (ATSDR) is conducting an epidemiologic case-control study of the children whose mothers were pregnant while living on base at Camp Lejeune from 1968-1985. ATSDR staff briefed Lt. General Kelly and other headquarters Marine staff on the status of the current study, including the water modeling component, in August 2005. The purpose of this letter is to seek your assistance in resolving outstanding issues that may delay ATSDR's ability to complete the current health study on time. The issues are as follows:

- ATSDR has experienced delays in obtaining requested information and data pertaining to historical water-quality sampling data and site remedial investigation reports. Attached for your information is a detailed list of these data, previously provided (during February – August 2005) to U.S. Marine Corps (USMC) Headquarters and Camp Lejeune staff, which outlines the needs of ATSDR to complete its water modeling activities;
- ATSDR staff has recently been made aware of the existence of a substantial number of additional documents, previously unknown and not provided to ATSDR staff. These documents are designated as "CLW" documents by the Camp Lejeune Environmental Management Division [EMD] and include summary data files and "document searching software" that could relate to and potentially impact our water modeling activities and analyses;
- The existence of a compilation of historical maps of water system changes at Camp Lejeune from 1941–2000. ATSDR needs to obtain these maps and all supporting spatial and temporal data files to assess the accuracy of ATSDR's understanding of historical changes in water-system configurations at Camp Lejeune; and
- ATSDR's need to have cooperation from and coordination with the USMC contractor currently engaged in a base-wide records discovery program. The contractor should be made

Lieutenant General Richard S. Kramlich
Page 2

aware of the types of records the agency is seeking and of ATSDR's water modeling and study completion time lines. We also request the timely sharing of these documents by your contractor to ATSDR.

ATSDR staff is attempting to meet the project completion timelines discussed with Marine Corps staff in August. To do so, we must be provided all documents that relate to base-wide water issues immediately. The Marine Corps is responsible for the identification and timely sharing of all relevant documents relating to the base-wide drinking water system. This includes documents that ATSDR may not be aware of as well as documents that are in the possession of DOD but may no longer be located at the Camp Lejuene base. Discovery of this documentation must not rely on specific requests from our staff, but on our shared goal of ensuring the scientific accuracy of our study and DOD's responsibility to provide the information. ATSDR staff can coordinate with USMC staff to determine the appropriateness of any document as it relates to our study. We request that your staff verify and confirm the existence of the documents listed in the attachment. We also request that your staff identify for us any other documents that may be useful to ATSDR for its water modeling analyses and make them available to ATSDR by December 31, 2005. In addition, we request that ATSDR be provided with any information or data that may be discovered at a future date that may have a bearing on our water modeling activities (e.g., information on water system interconnections and the actual production dates for supply of water from the Holcomb Boulevard water treatment plant).

A thorough review and assessment of such a large volume of documents at this late date and the incorporation of related information into nearly complete model investigations and analyses may require additional funding to review these documents and modify our model analyses if necessary. Completion of this assessment and required modifications to our model analyses may extend the timeline for the current health study by an additional 6 – 12 months.

If you or your staff have questions or would like to further discuss this matter, please contact Dr. Frank Bove, Senior Epidemiologist, Surveillance and Registries Branch, Division of Health Studies, ATSDR at (404) 498-0557.

Thank you again for your cooperation and continued interest in the work of ATSDR.

Sincerely,

Thomas Sinks for

Howard Frumkin, M.D., Dr.P.H.
Director, National Center for Environmental
Health/Agency for Toxic Substances and
Disease Registry

Appendix D

Public Statement by Department of the Navy Representative Dr. Dan Waddill

Department of the Navy Statements for the Expert Panel Assessing ATSDR's Methods and Analysis

for

Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point, Holcomb Boulevard and Vicinity US Marine Corps Base, Camp Lejeune, North Carolina

- **Introduction**

  My name is Dan Waddill, PhD, P.E. and I'd like to thank you all and ATSDR for this opportunity to address this Expert Panel for Hadnot Point and Holcomb Boulevard. I work in the Navy's Environmental Cleanup program as the head of the Engineering Support Section at NAVFAC Atlantic. My group provides technical support for investigation and remediation of Navy and Marine Corps sites across the continental United States and Alaska. My educational background is in modeling of groundwater flow and contaminant transport, and I've been involved in applying these models at numerous Navy and Marine Corps sites. Last year, I contributed to Navy comments on the ASTDR Water Modeling Report for Tarawa Terrace, and I believe you have copies of these comments and responses.

  The Navy and Marine Corps fully support the scientific effort to determine exposure concentrations and their effects at Camp Lejeune, including Tarawa Terrace and Hadnot Point / Holcomb Boulevard. In particular, we support the work of this expert panel, and we thank you for your efforts. As you move forward with your discussions today and tomorrow, I'd like to ask you to consider 3 issues related to the groundwater modeling efforts.

- **Definitions: Accuracy versus Precision**

  However, before I get to the 3 issues, I'd like to explain how I will use the words "accuracy" and "precision" with respect to model output. I think this will help clarify my comments that follow. **Accuracy** is the extent of agreement between model output and measured data. Accuracy would be estimated by comparing the model to the real world. For example, at Tarawa Terrace, we would compare model-simulated PCE concentrations to measured PCE concentrations to get a sense of model accuracy. **Precision** is the extent of agreement among various model runs. Precision would be estimated by comparing one model run to another as, for example, during sensitivity analysis or Monte Carlo analysis.

- **Issue 1—Data Availability.**

  In the existing charge to the panel, Section 2b says, "Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations." In addition to working on that question, I ask the panel to consider a more preliminary issue; that is, **whether or not modeling at Hadnot Point is capable of providing reliable average concentrations on a month by month basis**. In other words, can we expect the model to distinguish concentrations from one month to the next with a degree of accuracy that's useful for an epidemiological study? Or is monthly output simply a finer resolution than modeling can achieve?

  Why consider this issue? We know the modeling efforts for Tarawa Terrace and Hadnot Point both face a fundamental difficulty caused by the limited availability of real world concentrations. The

models must reconstruct historical concentrations back to the 1940's or 50's, but prior to the 1980's there are no measurements of PCE, TCE, and the other contaminants.

For Tarawa Terrace, ATSDR determined (and Navy agrees) that there was not enough measured PCE data for a meaningful model verification step. Since measured PCE concentrations are available only in the 1980's, model output from the early 1980's back to the 1950's cannot be compared to actual PCE data. That's roughly 30 years during which the model output at Tarawa Terrace cannot be verified.

To evaluate uncertainty, probabilistic analysis was used at Tarawa Terrace. Numerous model runs were compared against each other, giving an idea of uncertainty based on model *precision*. This is good information, and probabilistic analysis is a standard modeling approach. Nevertheless, probabilistic analysis cannot tell us how *accurately* the re-constructed concentrations would match the real world exposures that occurred in the past. It gives us a sense of how tightly clustered the model output is, but it doesn't tell us if that cluster of simulated concentrations are hitting the real world target.

For Hadnot Point, the situation is similar in that the model would need to extrapolate concentrations back in time for roughly 30 to 40 years. However, as we know, the Hadnot Point site is much larger and significantly more complicated than Tarawa Terrace. Overall, these difficulties and uncertainties raise the issue of whether or not modeling at Hadnot Point is capable of providing reliable average concentrations on a month by month basis. Or will the uncertainty be so great that month by month concentrations cannot be distinguished?

- **Issue 2—Uncertainty.**
  For the second issue, I'd like to look more closely at model uncertainty. As I mentioned before, at Tarawa Terrace, probabilistic analysis was used to examine uncertainty with respect to the *precision* of the model output. This work occurred within the model world, as model runs were compared to each other. However, we also need to examine how the model compares to the real world, as this will help us understand uncertainty with respect to model *accuracy*. Obviously, there are long stretches of time without real world data for comparison, but measured concentrations are available during the 1980's. At Tarawa Terrace, this information was used during model calibration to assess the match between the model and the real world. This match, or degree of fit, gives an estimate of uncertainty with respect to model accuracy during the 1980's. For the earlier decades without real world data for comparisons, accuracy is somewhat unknown, but I don't think we can assume the model would be more accurate in the 1960's or 70's than it was shown to be during the 1980's. But that is for you to decide. Basically, I would just like to ask the panel to consider uncertainty with respect to model accuracy as well as model precision, and to **consider how uncertainty in model accuracy can be assessed and conveyed to the model users, including the public and the epidemiologists**.

  For example, this morning when Dr. Bove showed the table of monthly, model-derived exposure concentrations, the panel commented that 3 significant digits may not be justified, and that it may be more appropriate to show a range of values rather than a single number. I believe these are good suggestions that would appropriately and usefully convey uncertainty to the public and the model users. As an illustration (just picking some numbers), it would be helpful to know whether a value of 90 μg/L falls within a range of 60 to 150, or 30 to 300, or 10 to 1000.

- **Issue 3—Model Calibration.**
  For the third issue, I'd like to look more closely at model calibration. The existing charge to the panel asks whether there are established guidelines for applying calibration targets and what the calibration targets ought to be. Given that approach, I'd like to ask the panel to **consider also how model results ought to be interpreted if the calibration targets aren't met**. For example, at Tarawa Terrace, calibration targets were chosen such that a model-derived PCE concentration could be roughly 3 times higher or 3 times lower than the measured concentration and still be within the calibration range. After calibration, simulated concentrations fell outside the calibration range for 12% of the results at the Water Treatment Plant and 53% at the water supply wells. Perhaps a more general and useful approach would be to **consider how the performance of the model during calibration should be assessed and convey to model users**. I believe this issue is important because it sheds light on model accuracy, and it helps users understand the uncertainty with respect to accuracy.

- **Summary**
  In summary, I ask the panel to consider 3 issues:

  1. Given the limited availability of measured concentrations, and given the site-related difficulties and uncertainties, would modeling at Hadnot Point be capable of providing reliable average concentrations on a month by month basis?

  2. In addition to uncertainty with respect to model precision, how should uncertainty with respect to model accuracy be assessed and conveyed to the model users?

  3. How should the performance of the model during calibration be assessed and conveyed to the model users?

  Issues 2 and 3 can actually be lumped into one primary objective, which is to give the public and the epidemiologists a clear understanding of model uncertainty. At the end of the day, I believe we all share a common goal, which is for the epidemiological study to be supported by the best available science. We very much appreciate your efforts and recommendations toward reaching that goal.

Appendix E

Panel Members' Premeeting Comments[14]

[14] Premeeting comments are presented in the format provided by panel members and have not been changed or modified by ATSDR.

Ann Aschengrau, ScD

Preliminary Comments

Based on the information provided by ATSDR, I believe that all of the scientists working on this incredibly complex project need to be commended for their outstanding job. It is clear that they have gone beyond the state-of-the-art for examining health effects of environmental pollution in an epidemiological study.

That said, I have a couple of concerns about the study that may inform the decisions that need to be made by the Expert Panel.

a. First are the very small sample sizes of the birth defect and childhood cancer case groups. This means that any exposure misclassification will have a relatively large impact on the measures of association. In other words, misclassifying couple of cases as exposed if they are truly unexposed or vice versa will have a large impact on the study results. Thus, any decisions regarding the exposure assessment must maximize both its sensitivity and specificity. In fact, specificity may be more important than sensitivity.

b. Second is the need to perform quantitative sensitivity analyses regarding all major exposure assessment decisions. For example, regarding the transfer of drinking water from Hadnot Point to Holcomb Boulevard (Question 4), various scenarios should be considered before settling on a preferred option. These scenarios range from ignoring this source of contamination to considering it present for the entire summer.

c. Third, I suggest extending the exposure assessment period for the childhood cancer cases from the first year of life to the time of diagnosis. This will enable a more robust analysis that can consider a range of cancer latency assumptions.

I am looking forward to our discussion at the upcoming meeting and expect to have additional comments at that time.

E. Scott Bair, PhD[15]

Written Comments

(1). Based on the materials from the Tarawa Terrace modeling and the discussions at the Expert Panel Meeting in late April, there is a great deal more geologic and hydrologic information that could be squeezed from the available datasets. The geologic framework of the Hadnot Point (HP) and Holcomb Boulevard (HB) area of the base used in the preliminary groundwater models is overly simplified. If additional geologic information is added to the model, it will help constrain the model and reduce uncertainty. These additional data: analysis of aquifer tests and slug tests to determine spatial changes in hydraulic conductivity and specific yield, calculation of uniformity coefficients (D_{60}/D_{10}) from sieved sediment samples to help identify confining beds and spatial changes in lithology (and physical properties) of aquifer units, determination of baseflow discharge to streams (local and regional) to help estimate temporal variations in recharge, and analysis of geophysical logs to determine the connectivity and continuity of aquifers and confining beds.

(2). Using a uniform hydraulic conductivity of 1.0 ft/d in all confining layers is not realistic. Neither is using a uniform effective porosity of 0.20 in all confining layers and aquifer units. Use of site-specific values will improve both the flow model and the contaminant transport model. Use of site-specific values will also lower the uncertainty and skepticism associated with use of uniform values.

(3). In the preliminary flow model and transport model, allocation of pumping rates to penetrated aquifer units in supply wells was not done in a manner that properly accounted for differences in the thickness and hydraulic conductivity of these permeable units. As a result, unrealistic pumping rates likely were assigned in the model. This causes some aquifer units to be locally overpumped and others to be underpumped resulting in unrealistic drawdowns and lateral and vertical hydraulic gradients, which in turn would result in unrealistic movement of contaminants across confining beds and through aquifer units to the supply wells. An effort should be made to weight the pumping rates assigned to each aquifer unit penetrated by a supply well by the local transmissivity of that aquifer.

(4). In the preliminary model, layer 1 lumps too many hydrostratigraphic layers. By not delineating minor confining units within these sediments, the contaminant transport model will unrealistically move contaminants too rapidly through the flow system, especially at the source areas.

(5). If DNAPL is present at some source areas, the continuous creation of dissolved phase contaminants from the DNAPL at depth needs to be accounted for in the contaminant transport model by adding source terms to underlying model layers so the dissolved phase continues 'to enter' the model.

(6). The final transient model needs to account for prolonged droughts and wet periods. This is especially important if these periods occur during the 'recharge phase' of the annual hydrologic cycle when vadose water is moving downward to the water table. Generally, the recharge period occurs between November and April. Precipitation during this time of year generally is not in the form of local thunderstorms and is more regional in occurrence and impact. Nearby airports and weather stations can help guide the application of greater or lesser amounts of recharge to the flow model during exceptionally wet and dry periods. USGS records of stream baseflow from nearby or regional streams also can help identify wet years and dry years.

[15] Dr. E. Scott Bair provided his premeeting comments in May 2009, after the completion of the panel meeting.

(7). Figure A16 in Chapter A—If figures like this are to be used in the future, it would be worthwhile to remove the misleading portrayal that Northeast Creek cuts down into model layers 3 and 5. From what I have read these geologic units are continuous beneath the creek.

(8). Figure A16 in Chapter A—This too is a comment for future work based on what is shown on this figure. The box identifying ABC Cleaners leads readers to think the source term for the PCE are solely is model layer 1. If there is free product at depth beneath the cleaners, then source terms should be introduced in deeper model layers and described in the text and any associated figures.

(9). Figure A18 in Chapter A—If a figure similar to this one is to be used in future reports, the y-axis should be cut off at a concentration of 0.1 or 1.0 µg/L. Any simulated concentrations lower than this likely are dominated by numerical dispersion in the solution scheme, not by hydrodynamic dispersion in the flow system. The same can be said for the y-axis on Figure A19. This would be consistent with the contour maps of contaminant concentrations that start at contoured value of 1.0 µg/L, as shown on Figure A20, and the y-axes on Figures A11 and A12, which start at a level of 0.1 µg/L.

(10). The next generation of models would benefit from having some 'flux data' with which to calibrate the model. Calibration solely to measured heads is limiting. Having streamflow gain and/or streamflow loss information or isotopic data (CFCs or tritium/helium) yielding ground-water ages can substantially improve calibrations and provide greater confidence in model predictions.

(11). Use of MODPATH to visualize flowpaths and traveltimes is an important part of any modeling effort. It is easy and quick to use and provides the modeler and field personnel with a visual representation of the flow system that looking at head maps cannot provide. It also is an easy way for non-professionals to visualize the flow system—most lay people to do not think in terms of equipotential contours and the inference that flow is perpendicular to them, let alone that equipotential lines refract at changes in permeability. Use of MODPATH and its many options for identifying recharge areas, discharge areas, traveltimes, and flowpaths should be included in future efforts.

(12). Future sensitivity and uncertainty analyses should also address the plausible ranges in source concentrations of TCE/PCE and plausible temporal variations in the first release of contaminants from source areas.

(13). Readers would benefit from an appendix that lists measured permeability values, the type of test performed, method of analysis, and a the literature citation. A similar table of porosity values also would be beneficial.

(14). As the geologic materials underlying Camp Lejeune are fluvial in origin and old enough to have experienced compaction and cementation, some anisotropy needs to be added to individual model layers. Any sediment deposited in water is anisotropic ($K_h > K_v$) because of differences in grain sizes and settling velocities. In addition, the cross cutting nature of aggrading stream channels and their associated floodplain deposits create anisotropic conditions on a larger scale.

Richard Clapp, DSc

Initial Response to Charge Questions

1a. No modifications or changes to the data analysis plan for quantification of historical concentrations of contaminants in drinking water are recommended at this point.

1b. No modifications or changes to the groundwater flow and contaminant fate and transport are recommended at this point.

1c. Uncertainty bounds for the distribution of drinking water under certain "worst case" scenarios should be estimate, if possible. For example, the addition of the Hadnot Point to Holcomb Boulevard periodic transfer in June should be accompanied by an estimate of the uncertainty introduced by this addition to the model.

2a. The estimation of uncertainty or computation of uncertainty bounds under specific scenarios may be quite computer-intensive. If it is not feasible, then the estimation may not be done, but reasons should be explained.

2b. The "all pipes" model used for Tarawa Terrace should be used in Hadnot Point and Holcomb Boulevard, if possible. If the latter two systems are too complex to lend themselves to this method, then a "simple mixing" model should be used.

3a. I am not aware of established guidelines for fate and transport modeling calibration in a project such as the Camp Lejeune project.

3b. If ± one-half an order of magnitude is not achievable, then ± one order of magnitude can substituted for Hadnot Point and Holcomb Boulevard modeling.

4a. Simple mixing appears the most sensible approach, given the uncertainties and lack of detailed records of these intermittent transfers.

4b. A "typical" month, such as June, would make the most sense for this simulation.

4c. A worst-case scenario might be for pre-natal exposure during June, among children exposed while their mothers were residing at Hadnot Point or Holcomb Boulevard. This may not apply to any of the children with leukemia, for example, but it would be a scenario worth examining.

5. No change in the target date is recommended at this point.

Robert M. Clark, PhD, PE, DEE

Response to Expert Panel Charge

This is my response to the "Charge to the Expert Panel" issued by ATSDR. The ATSDR is requesting the expert panel's opinion with respect to five basic questions and I have addressed each question in order.

Question 1: Based on information provided by ATSDR to the panel, are there any modifications or changes that ATSDR should consider making in its response to quantifying historical concentration associated with:

a. Data analysis?
b. Groundwater flow and contaminant fate and transport?
c. Distribution of drinking water?

Response:

Data Analysis

I have reviewed the documents sent to me by ATSDR (ERG) and, based on my review, believe the ATSDR study team has explored most of the available data that is relevant to quantifying historical concentrations associated with the contamination (and subsequent exposures to Volatile Organic Chemicals) that occurred at the U.S. Marine Corps Base, Camp Lejeune, North Carolina. During my career with USEPA I was involved with conducting waterborne disease investigations and appreciate the difficulties faced by ATSDR in collecting and analyzing exposure data from drinking water systems. The problem of identifying the factors causing acute disease from waterborne contaminants, which is the problem we faced, is very similar to the problems associated with identifying the factors causing the in utero and birth defects discussed in this study. However attempting to link VOC exposures to chronic effects such as leukemia adds a layer of complexity to the task and is extremely challenging. ATSDR faces the same issues (we faced) of using historical data to estimate the health effects in a population exposed to a potentially harmful agent in drinking water. One of the major issues in conducting this type of study is model calibration. From a scientific viewpoint it would be ideal to have independent data sets. One set could be used to calibrate the models and the second data set used for validation. If one is developing a model based on experimental data this approach can be built into the combined experimental and modeling effort. However, it has been my experience that such an ideal situation rarely exists in "real world" situations. Therefore, in my opinion, the best approach is to use available datasets in conjunction with sound engineering principles and the investigator's best judgment to establish the validity of the exposure models.

I was very interested to see the very high levels of PCE and TCE which were found in the Tarawa Terrace and Hadnot Point well waters. Both levels exceed current MCLs and I am curious about the circumstances that led-up to these findings. Based on my understanding these values were found during a special study conducted in 1985. However, the MCLs for these compounds were not established until much later and at the time of the survey the VOC methods for drinking water were being developed. How and why were these data collected and were the analytical methods used considered to be reliable? Given the fact that these data play a critical role in the reconstruction studies I think some discussion of these issues would be useful. It occurred to me that THM samples were also being taken at the water treatment plants at the same time. These THM samples were probably started in the late 70's. THMs are volatile and it is likely that some of the THM data may also reflect the presence of other VOCs in the samples. It might be possible to estimate the THM levels that would

be expected in the Camp Lejeune ground waters and subtract these expected values from the sampled THM values. I found nothing in any of the reports on the type of treatment practiced at Camp Lejeune but I think a brief description would be helpful.

A point that was not addressed, in the documents I received, is the potential dermal and inhalation exposures that most likely occurred in the residences on the base. Some of the sampled VOC levels approach industrial exposures. Was data from the occupational and industrial exposure literature for VOCs examined? Compartment models are available that could be used to simulate household inhalation exposures. We conducted such a study using THMs as the target. I reference a couple of papers at the end of my response. It seems to me that the issue of adult exposures and the need to follow-up with both adult and childhood health effects should be addressed.

I am curious about the fate and transport of some of the degradation by products in the groundwater samples. This was addressed in depth in any of the reports I reviewed and might be a consideration in the Hadnot Point studies. It strikes me that some of the degradation byproducts may be more of a problem then the original compound.

Groundwater flow and contaminant fate and transport

The ATSDR study has conducted a very detailed analysis of the groundwater fate and transport characteristics of the Camp Lejeune site as recommended by the 2005 Expert Panel. They have:

- Conducted an extensive study of the available hydrogeologic data available for the Castle Hayne aquifer system
- Used MODFLOW-96 to examine the steady-state groundwater flow prior to the drilling of water supply wells in the Camp Lejeune study area
- Used MODFLOW-96 to examine the unsteady-state flow characteristics in the Camp Lejeune site that occurred after the initiation of well drilling activities and during the operation of the wells.
- Examined the properties of the degradation pathways of common organic compounds in groundwater.
- Made estimates of the mass volume of PCE in the unsaturated zone and within the Tarawa Terrace and Upper Castle Hayne aquifers.
- Simulated the fate and migration of PCE from its source (ABC One-Hour Cleaners) using the MT3DM3 model.
- Estimated the exposure concentrations of PCE in the water delivered from the Tarawa Terrace water treatment plant using results from the fate and transport model.
- Assessed the arrival times of PCE at the Tarawa Terrace WTP using the PSOps model.
- Examined the fate and transport of PCE and degradation by-products using TechFlowMP.
- Conducted an extensive assessment of groundwater flow parameters under uncertainty using Monte Carlo simulation techniques (PEST model).

The analysis applied to the Tarawa Terrace area was very impressive but given the nature and the spatial dispersion of the contamination sources in the Hadnot Point area it may be difficult to develop a similar model. If a simpler model can be developed to give equivalent results I think such an approach would be desirable. If a simpler analytical framework is developed then I suggest it be tested and calibrated against the Tarawa Terrace simulation to be sure they are equivalent.

Distribution of drinking water

Initially the ATSDR conducted an extensive calibration study and applied the public domain model, EPANET 2 to simulate street-by-street PCE concentrations in the Tarawa Terrace area. However, the previous expert panel (2005) recommended the use of a simple mixing model based on continuity and conservation of mass. The ATSDR team tested the mixing model against the EPANET results and found the results to be equivalent in terms of exposure predictions. However, given the nature of the intermittent exposures in the Holcomb Boulevard area due to interconnections with the Hadnot Point area, I suspect that the ATSDR team may have to conduct more detailed simulations to understand the exposures that occurred in the Holcomb Boulevard area. A mixing model may work for the Hadnot Point area however.

Conclusions

In my opinion the ATSDR team has conducted a very professional, and thorough simulation of the exposure levels associated with contamination in the Tarawa Terrace service area. The re-creation of historical exposure levels is always very challenging and in this case, considering the span of time involved and the dynamic nature of the exposed population, this situation is far more challenging than any we faced in our work.

I found the ATSDR predictions very believable and scientifically credible and compliment them on their efforts. Drawing public health conclusions will be difficult, however. My recommendation is that ATSDR apply a simpler approach to groundwater fate and transport in the Hadnot Point and Holcomb Boulevard service areas but consider an all-pipes model to simulate finished water exposures.

Question 2: ATSDR has provided panel members with summaries of information, data and preliminary analysis that will be used for reconstructing historical contaminant concentrations at Hadnot Point, Holcomb Boulevard, and vicinity.

a. What data analysis and modeling complexities do panel members anticipate and what are their concerns?
b. Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations?

Response:

Data analysis and modeling complexities

I am not an expert on groundwater modeling methodology but it seems to me that the ATSDR team should explore using the same or similar methodology to that applied to the Tarawa Terrace exposure study, if possible. However, I suspect that modeling a larger area with more sources of contamination and then interfacing these models with the Hadnot Point and Holcomb Boulevard distribution system models will provide some difficult challenges. A simpler model may be the most practical approach.

It seems to me that because Hadnot Point was periodically interconnected to the Holcomb Boulevard an all-pipes model will be required along with more detailed demand scenarios to properly characterize these interconnections.

Recommended modeling methods

Ideally, the ATSDR team should attempt to apply the same approach to Hadnot Point and Holcomb Boulevard as applied to Tarawa Terrace. However, based on my review of the documents I was

provided, the more practical approach may be for ATSDR to consider using a simpler model for the Hadnot Point and Holcomb Boulevard groundwater simulations. If this simpler approach is taken then I suggest that this simpler model be applied to the Tarawa Terrace area to determine if it gives similar results and use the Tarawa Terrace experience as a calibration point. However, I suspect that the water distribution system models for Hadnot Point and Holcomb Boulevard will have to be more complex then the simple mixing model used for Tarawa Terrace. My suggestion is that for these two systems an all pipes model be used.

Question 3: ATSDR established a calibration target of ± ½ order of magnitude for comparing measured and simulated water-quality data for the Tarawa Terrace contaminant fate and transport model.

a. Are there established standards or guidelines in the fate and transport modeling community for determining and applying specific calibration targets? If so, what are those standards or guidelines?

b. If ATSDR should establish different calibration targets for Hadnot Point, Holcomb Boulevard, and vicinity (compared to targets used for the Tarawa Terrace model), what should the calibration targets be?

Response:

Established standards or guidelines

To my knowledge there are no established standards or guidelines for modeling the fate and effect of contaminants. However the ASTDR target seems very reasonable to me. In general it seems, to me that the ATSDR team has achieved its objectives.

Calibration targets for Hadnot Point and Holcomb Boulevard

I believe it is reasonable for ATSDR to maintain the same calibration targets as were used in the Tarawa Terrace model and apply them to the Hadnot Point and Holcomb Boulevard modeling efforts.

Question 4: ATSDR has been provided with information that Hadnot Point drinking water (contaminated) was periodically transferred to the Holcomb Boulevard water-distribution system (non-contaminated drinking water) during the period 1972–1987 (typically for a few hours during April, May and/or June). This may require the use of a water distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.

a. Because the water transfers occurred intermittently, which water-distribution system modeling approach do panel members recommend as the most sensible and reliable for estimating monthly mean historical concentrations (e.g., simple mixing or an all-pipes model)?

b. Because continuous descriptions of the date and duration of the water transfers are not available, do panel members recommend simulating the spatial distribution of historical drinking wafer concentrations solely for a "typical" month (e.g. June) during these years?

c. Given the intermittent supply of contaminated Hadnot Point water to the Holcomb Boulevard water-distribution system, what simulation scenarios do panel members recommend be developed to provide exposure concentrations for use by the epidemiological study?

Response:

Intermittent transfers between Hadnot Point and Holcomb Boulevard

For purposes of analyzing the interconnected systems my suggestion is to use an all-pipes model

Simulating spatial descriptions of drinking water concentrations

It is not clear to me if there is sufficient information to simulate the changes in population that might have occurred over the study period. If such data are available then I suggest they be incorporated into the model. I assume that most of the water demand in both service areas is domestic but I would be sure that any non-domestic water demand is incorporated into the various modeling scenarios. For example, if there is light industrial, irrigation or lawn watering demand components they should be included. Another consideration might be to explore the application of the Poisson Response Pulse (PRP) method developed by Dr. Steve Buchberger at the University of Cincinnati. The PRP method essentially simulates household demand. Other use patterns such as industrial and irrigation use could be superimposed on the household patterns and then monthly simulations developed for each system for the study period. I doubt if a typical month in a year will be adequate. After these independent simulations are developed than I would superimpose the interconnection pattern and hopefully that would provide some indication as to how far the contaminated water form Hadnot Point penetrates into Holcomb Boulevard.

Simulation Scenarios

Once time-weighted monthly simulations have been develop for each service area then I would look at the effect of line and hydrant flushing, house or building fires, street washing, line breaks and repairs. It seems to me that peak water-use events especially during interconnection periods will provide the maximum exposure scenarios.

Question 5: ATSDR has set a target date of December 2009 for completing historical reconstruction modeling tasks for Hadnot Point, Holcomb Boulevard, and vicinity. If, in the panel's majority opinion, ATSDR should modify the project tasks and schedule, what specific activities does the panel suggest ATSDR modify and how should the project schedule be modified?

Response:

I am assuming that based on previous work, the ATSDR team has acquired or synthesized a great of data that can be used to model the Hadnot Point and Holcomb Boulevard service areas. However, based on the work accomplished to-date, and from what I have seen so far it seems to me that finishing the exposure modeling by December 2009 will be very ambitious. I would prefer to wait until after the meeting of the expert panel to answer this question.

Summary and Conclusions

In summary I found the effort detailed in the Tarawa Terrace reports to be very impressive. However, there are few points I would like to highlight:

- It would Ideal to have independent data sets for calibration and validation. This is almost imperative for controlled or experimental studies. However, based on my experience this goal is probably not practical for retrospective studies. It seems to me that the best alternative is to use sound engineering principles, and the best scientific and engineering judgment while incorporating the best data available.
- Prior to 1985 the water plants at Camp Lejeune would have been measuring THMs (probably after 1976). Could these data be used to estimate VOC levels in the Camp Lejeune water supply? Has there been any review of the methods being used for VOC analysis at that time?
- The VOC levels shown for Tarawa Terrace and Hadnot Point are close to industrial and occupational exposure levels. Has any effort been made to look at the literature in this area?
- Given the VOC levels found in the Tarawa Terrace and Hadnot Point service areas has there been any effort to model household exposures including dermal and inhalation exposures? Has there been any attempt to follow-up on health effects in adult populations?
- It seems to me that modeling the Hadnot Point and Holcomb Boulevard ground water simulations may require a more simplified model then used in Tarawa Terrace. However I suggest the simplified Hadnot Point and Holcomb Boulevard models be calibrated against results from the Tarawa Terrace model.
- I believe an all pipes model will be required to simulate the interconnections between Hadnot Point and Holcomb Boulevard. The PRP approach with other demand patterns superimposed might be investigated for simulation purposes.

Possible References on Modeling Household Exposure

Clark, R.M., Rossman, L.A. and Goodrich, J.A., 1992, Modeling the variation in human exposure to contaminants from drinking water: Journal of Exposure Analysis and Environmental Epidemiology, Suppl. 1, p. 159–175.

Clark, R.M., and Goodrich, J.A., 1992, Modeling Human Exposure to Contaminants from Drinking Water: Journal of Water Supply Research and Technology-Aqua, v. 41, no. 4, p. 224–230.

David E. Dougherty, PhD

Pre-Meeting Comments and Questions

A. Groundwater Modeling and Epidemiological Study Requirements

1. Response 10.2(3) of the ATSDR "Response to the DON Letter" (10 March 2009) states "that a successful epidemiological study places little emphasis on the actual (absolute) estimate of concentration and, rather, emphasizes the *relative* level of exposure." Please discuss the nature of the relative concentration (e.g., linear or logarithmic) preferred for a successful epidemiological study.
2. The same Response goes on to say that "to infer which health effects occur at specific [contaminant] concentration...summarize[s] evidence from several epidemiological studies..." Presumably, an additional benefit of the current study is its potential utility for such an assessment at a later time. Please discuss the differences between the concentration-related needs of the current epidemiological study and of a potential future risk assessment.

B. Sources of Uncertainty

1. Rank and discuss the sources of uncertainty that are anticipated to have the greatest impacts on results (which would include, for example, concentrations, arrival times, variability in each).
2. Provide a detailed discussion of mass loading for the most significant sites. A brief description of the determination of mass loading rate for the Tarawa Terrace (TT) model would be a good jumping-off-point for the HPHB analysis.

C. Land Surface and Pre-Development Information

1. Please show a map, on the same scale and with the same contour values as the predevelopment head map (Notebook Tab 6, second slip-sheeted section, Figure 1), showing surface elevations. (Use a different color than black to allow overlays.) If there have been any significant cut or fill activities over the reconstruction interval, indicate where they have occurred.
2. Are there any topsoil or vegetative cover features that may impact the distribution of infiltration?

D. Stratigraphy

1. For the significant contamination sites, do cross-sections exist that show the strata, water supply well screen(s), boring log(s), and plume (contours or posted data)?

E. Model Gridding and Time-Stepping

1. How and where will refined flow meshes be used in flow modeling?
2. What gridding will be used for transport modeling?
3. Will a single transport model be constructed, or will a set of local transport models be used?
4. What time-stepping and advection schemes will be used?
5. For each of the significant contaminant source areas, please provide figures showing grid, water supply wells, and current/recent estimated plume and/or DNAPL distribution; drainage features, surface elevations, and any other features would help orient the viewer.

F. Groundwater Flow and Head Modeling

1. What head calibration targets will be used? The same as for the TT work?
2. Notebook Tab 6, second slip-sheeted section, page 5 discusses the trial-and-error reduction of infiltration from 13 in/yr to 8.8 in/yr an simultaneously reducing the horizontal conductivity from 13.5 fpd to 5 fpd as a way to reduce unrealistically flooded cells.

3. Notebook Tab 6, second slip-sheeted section, page 5 introduces the PEST objective function √. Please define it.
4. Use the same contour values on Figures 1 and 3 of Notebook Tab 6, second slip-sheeted section.
5. The steady flow calibration figure (Notebook Tab 6, second slip-sheet, Figure 4) indicates that there is a bias in the model results for supply wells—the simulated head exceeds observed water levels. Because this is not apparent in the TT calibration results (Figure A10 from Chapter A report on TT), please discuss the difference in bias?
6. In Notebook Tab 6, second slip-sheeted section, add a table comparing all of the initial and final parameter values for both the trial-and-error solution and the results of PEST calibration.
7. Notebook Tab 6, second slip-sheeted section, Table 1: Explain the use of LGR for flow models in contaminated areas. Also explain the item called "Design and calibrate fate and transport models." Is the sat-unsat model, which was used in the TT work, going to be used?

G. Concentration Modeling

1. Chapter A of the Tarawa Terrace study discusses the use of ND (nondetect) data to establish calibration targets. The detection limits listed in Table A9 drew attention, as some of them seem to be high. For example, the February 1985 result for TT-25 of 0.43J is inconsistent with a detection limit of 10. Are they "less-than" data (e.g., <10) in the original source tabulations or laboratory results? Are these detection limits or reporting limits? Because there are multiple types of these (as well as multiple types of quantitation limits), which ones are these?
2. Is the same approach to specifying a calibration range for ND data going to be used for HPHB? Should two locations—one of which has always had ND data and a second of which has had both ND and quantitated results—be treated the same?
3. Notebook Tab 5, Section 4.3 presents bioreaction rate constants, $k_{bioreaction}$ in equation (3). This is inappropriate because the rate constant is trying to capture too many processes and not just biologically mediated reactions. It also is neglecting location within the degradation chain (e.g., parent and child constituents for DCE). More succinctly, it isn't clear what this section is attempting to do.

H. Sensitivity and Uncertainty Modeling

1. What sensitivity runs will be performed?
2. What are the uncertain parameters, the types of distribution, and the truncation limits for each?
3. Comment 10.1 of the ATSDR "Response to the DON Letter" (10 March 2009) expresses concern with the number of Monte Carlo simulation realizations. The response suggests that the diagnostic control charts ensure that a sufficient number of Monte Carlo runs were performed. Based on the materials provided, and subject to the response to the preceding comment, it seems that there will be a greater number of significantly uncertain parameters, which implies a higher dimension probability integral and hence a higher required number of sample points. Discuss the procedure for the Monte Carlo sampling. Will stratified sampling (Latin Hypercube) be used? How many runs are anticipated?

I. Schedule

1. The schedule under Notebook Tab 3 indicates that only transport simulations, uncertainty assessments, and reporting remain. It also indicates that these tasks are starting immediately. Is this schedule still current?
2. The schedule indicates Element 2.14 will apply a Kalman filter to statistical analysis of field data. There seems to be no discussion of this Element.

Rao S. Govindaraju, PhD

Comments

Charge

Given the state of the science for reconstructing historical levels of contaminants in drinking water for the purpose of estimating human exposures, do the data analysis and computational methods used and proposed by ATSDR provide an adequate level of accuracy and precision?

The amount of work and the kind of analysis done thus far by ASTDR is quite impressive. My overall impression is that the modeling effort is providing the level of precision that could be achieved with the quantity and quality of data. The question of adequate level of precision must be addressed by the end use of this exercise. The current study should be able to provide suitable guidance for the subsequent epidemiological study.

ATSDR—Questions for the Expert Panel

1. Based on information provided by ATSDR to the panel, are there modifications or changes that ATSDR should consider making in its approach to quantifying historical concentrations:
    a. Data analysis?
    At the meeting, I was made aware that more data have been found. ATSDR needs time to analyze this information.
    b. Groundwater flow and contaminant fate and transport?
    The models chosen for groundwater (MODFLOW) and contaminant transport (MT3D) are appropriate. These models have been well-tested, have a long history of use, and enjoy a high degree of credibility in academia and industry.
    c. Distribution of drinking water?
    Similarly, the choice of EPANET is perfectly acceptable.
    d. What changes in its approach, if any, should ATSDR consider?
    Overall the models chosen are adequate for the overall task at hand. The methodology is rigorous but is again limited by the data. I will reserve comment on changes in approaches for later after the meeting, but at this time it looks fine.

2. ATSDR has provided panel members with summaries of information, data, and preliminary analyses that will be used for reconstructing historical contaminant concentrations at Hadnot Point and Holcomb Boulevard:
    a. What data analysis and modeling complexities do panel members anticipate and what are their concerns?
    The question of reconstruction of past concentration histories given the limited data is inherently an uncertain process. In such situations, data uncertainty, model uncertainty, and parameter uncertainty exist in all studies. The authors use calibration to reduce parameter uncertainties, and a probabilistic analysis is conducted to assess the overall uncertainties. However, since no independent corroboration data set is available, a clear idea of the models' capabilities are difficult to assess. The issues of equifinality and non-uniqueness remain unresolved. During the calibration process, how many parameters were calibrated

and how many data points were available? The issue of degrees of freedom should be provided to convey a more clear sense of uncertainty.

The results need more discussion. It should be specified that the well concentrations are depth-averaged values depending on the screening interval. Thus, local concentrations in some of the individual layers could be higher. In Fig. 3 of the WQEH paper showing model concentrations, there are some sudden fluctuations that need to be explained. The authors state that sharp drops in concentrations are due to well pumping stoppages at TT-26, which is a key source. This explanation needs to be expanded further. Firstly, the concentration drops and rises are very rapid. Moreover, such changes should be more dramatic at the pumping well TT-26. However, no such sudden fluctuations are found in the corresponding concentration profiles in TT-26. In any event, a better explanation would help readers understand the results better. Similarly, in Fig. 4, the results are constrained in terms of their variability until Jan. 1960 by an initial condition of zero concentration in Well TT-26.

b. Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations?
One could suggest use of Bayesian methods, such as GLUE, but I am not certain that is warranted.

3. ATSDR established a calibration target of ± ½ order of magnitude for comparing measured and simulated water-quality data for the Tarawa Terrace contaminant fate and transport model.

a. Are there established standards or guidelines in the fate and transport modeling community for determining and applying specific calibration targets? If so, what are those standards or guidelines?
To the best of my knowledge, there are no accepted protocols for setting calibration targets. Typically, one sets calibration targets based on the available data and the goals of the study. Since the purpose of this modeling exercise is to reconstruct concentration histories for use in an epidemiological study, the modeling study should provide an estimate of human exposure. Ideally, this goal should decide the calibration targets. Is it that the individual concentration level that is toxic, or the dose experienced over a sustained period of time? It appears that the focus has been on concentrations. The same issue should govern whether ½ order of magnitude of tolerance for concentration values during calibration is sufficiently accurate.

The issue of calibration is quite complex-especially in the absence of a corroboration data set. ATSDR reports that a fraction (perhaps a substantial one) of the data fell outside this suggested band. Again, there are no established or accepted guidelines for these quantities in the modeling community.

b. If ATSDR should establish different calibration targets for the Hadnot Point and Holcomb Boulevard areas (compared to targets used for the Tarawa Terrace model), what should the calibration targets be?
If there are flow measurements, then they should be used as well. Metered data of water usage would be helpful in this regard.

4. ATSDR has been provided with information that Hadnot Point drinking water (contaminated) was periodically transferred to the Holcomb Boulevard water-distribution system (non-contaminated drinking water) during the period 1972–1987 (typically for a few hours during April, May, and/or June). This may require the use of a water-distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.

a. Because the water transfers occurred intermittently, which water-distribution system modeling approach do panel members recommend as the most sensible and reliable for estimating monthly mean historical concentrations (e.g., simple mixing, all-pipes model, etc.)?
This seems to be the question of skeletonization. A simple mixing model may not adequately capture the space-time evolution of concentrations. To be on the safe side, the all-pipes model should contain enough detail to faithfully capture exposure levels.

b. Because continuous descriptions of the date and duration of the water transfers are not available, do panel members recommend simulating the spatial distribution of historical drinking water concentrations solely for a "typical" month (e.g., June) during these years?
A typical month analysis would be useful and should be done, but this should be supplemented with similar analysis for what are judged to be critical months and non-critical months as well. A typical month would perhaps be a good estimate of the 'mean' or 'mode,' but it would be more accurate to reconstruct mass exposure with a distribution.

c. Given the intermittent supply of contaminated Hadnot Point water to the Holcomb Boulevard water-distribution system, what simulation scenarios do panel members recommend be developed to provide exposure concentrations for use by the epidemiological study?
Scenarios should be designed so as to be able to identify critical cases of exposure at one time, and on long-term cumulative exposure as either of these could be of concern.

5. ATSDR has set a target date of December 2009 for completing historical reconstruction modeling tasks for the Hadnot Point and Holcomb Boulevard areas. What specific activities, if any, does the panel suggest ATSDR modify and how should the project schedule be modified?
The schedule for completion of historic reconstruction activities is Dec. 2009. I believe ASTDR should give itself more time to respond to the concerns raised in the review panel meeting.

A few points of note:

- *Analyze recently found data.*
- *Provide more time to conduct the study.*
- *Regarding TechFlowMP—I have no problem if it is properly tested. However, it may be helpful to gain more acceptability by also justifying its use as opposed to "accepted" models.*

Walter M. Grayman, PhD, PE, DWRE

Initial Response to Charge Questions

I have reviewed the documents provided to me prior to the Expert Panel Assessing ATSDR's Methods and Analyses for Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point, Holcomb Boulevard and Vicinity, U.S. Marine Corps Base, Camp Lejeune, North Carolina. Following are my initial comments concerning the charge. I have focused on the area of contamination and processes within the water distribution system since this is my primary area of expertise.

Overview: The ATSDR team has done an excellent job to date on their analysis. In all cases, the methodology employed and the resulting analysis is consistent with or exceeds the norm for studies of this type. However, the recent discovery that Hadnot Point and Holcomb Boulevard systems were intermittently interconnected during the period 1972 to 1987 adds a level of complexity that will require some modification of the methodology when assessing the contamination and exposure within the Holcomb Boulevard system.

Analysis of Tarawa Terrace water distribution system modeling. I have reviewed the methodology used by ATSDR in the historical reconstruction of the movement of contaminants in the Tarawa Terrace distribution system. In my opinion, the methodology is (1) acceptable for the purposes of this study, and (2) meets or exceeds the commonly recognized practices in this area. Specifically, ATSDR has constructed a very detailed network model and employed advanced field and analysis techniques in the calibration and validation of the model. With the exceptions noted below, I feel that these same methodologies should be applied in the application of the model to the Hadnot Point and Holcomb Boulevard distribution systems.

Interconnection of Hadnot Point and Holcomb Boulevard systems. The recent discovery that an intermittent connection between the Hadnot Point distribution system and the Holcomb Boulevard distribution system during the period from 1972 to 1987 that could have led to contaminated water entering the Holcomb Boulevard system is a significant development that requires some modifications in the historical reconstruction process that has been used previously. This situation differs from the previous Tarawa Terrace analysis and the Hadnot Point case in that: (1) the interconnection, and as a result, the contamination appears to be a highly intermittent event; and (2) there appears to be only sparse information available on the actual dates and durations of the interconnections. Following are preliminary suggestions on methods of modifying the methodology to analyze the Holcomb Boulevard contamination situation.

1. ATSDR should make every effort to ensure that they have identified and collected any information that is available that will further define the dates, times and flows associated with the intermittent transfer of water from Hadnot Point to Holcomb Boulevard.
2. Because of the apparent relatively short-term (on the order of hours) nature of each period of water transfer, the contamination impacts on the Holcomb Boulevard system are likely to be quite transient. Consequently, the analysis will need to be at a temporally and spatially fine enough scale to capture these impacts. This would preclude the use of a simple mixing model since the system would not be expected to reach equilibrium during most transfer events (i.e., the concentration of the contaminant would not likely reach a constant value over the entire distribution system). As a result, the analysis will require the use of an all-pipes model.

3. The paucity of data on the interconnection events and the significant variability in transfer events suggests the use of some form of probabilistic simulation analysis (e.g., Monte Carlo simulation) rather than selection of a "typical" month. This will also lead towards exposure results that will be probabilistic rather than definitive statements of exactly when and where the contaminant traveled in the Holcomb Boulevard system.

4. The extension of the analysis to the Holcomb Boulevard area using a probabilistic analysis of the water distribution system will likely affect the proposed tasks and schedule. Though it may not require an extension beyond the December 2009 target date for completion of the Hadnot Point and Holcomb Boulevard reconstruction modeling tasks, it will likely require more intensive efforts in these tasks. Additionally, ATSDR should build in some time for an external review of the methods to be used in this probabilistic analysis.

Graphical schematic of history of interconnection and contamination. In reading the various reports on the project, I found it difficult to keep track of the timeline of when the systems were contaminated, when they were interconnected and when various treatment plants were on-line. I suggest that you prepare a set of schematic "cartoon" diagrams illustrating the various situations over the 1968–1985 timeframe showing when the various systems were contaminated and when they were interconnected.

Benjamin L. Harding, PE

Initial Comments

The comments that follow are based on my present understanding of the situation at Camp Lejeune and the approach used by ATSDR. They are preliminary and are provided for the use of ATSDR and the expert panel.

Charge

The charge provided to the Panel addresses the technical requirements of accuracy and precision. I think the Panel should also address whether the analyses and methods will be accepted by the interested parties and the public, and the degree to which the interested parties and public will have confidence in the results of the analyses and methods.

In answering this question the ATSDR and the Panel will benefit from comments provided on the Tarawa Terrace analysis by the public and interested parties such as the Department of the Navy.

Questions

1. Modifications or changes that should be considered by ATSDR

Data Analysis.

Well surface elevation—I would like to know why it is not possible to refine surface elevations of monitoring or production wells. The precision of "target" heads in monitoring wells is limited by the measurement of surface altitude from topographic maps. I don't understand why these surface elevations cannot be improved.

Surface recharge—ATSDR initially assumed a constant recharge of 13 in/yr. Recharge was treated as a parameter and adjusted during manual calibration to 8.8 in/yr. It is not clear if recharge was adjusted during automated calibration using PEST. Surface recharge can be estimated using common methods. At the very least, the calibrated recharge rate used in modeling should be compared to estimates of recharge obtained using hydrologic modeling. Although I am not familiar with the hydrology of this area I would expect that surface recharge would vary substantially on an annual and seasonal basis.

Contaminant source term—It does not appear that ATSDR made estimates of the amounts of contaminants disposed of in the ground based on the activities at the disposal points. Such estimates would serve as a point of comparison with contaminant mass calculated from contaminant concentrations in groundwater.

Groundwater flow and contaminant fate and transport.

See comments below related to well dispatch and calibration.

Distribution of drinking water.

One thing that is missing from the materials provided to me is a detailed schematic of the raw water collection system and the finished water distribution system. I have concluded with a fair degree of certainty that all of the wells supplying water to the Hadnot Point service area did so through the Hadnot Point WTP, but a detailed diagram would have made that fact very clear from the start.

I don't fully understand the way in which water "demand patterns" were developed for use in the water distribution model. Water balance methods and PEST were used to reconstruct demand patterns. I'm not sure how these patterns were to be used to reconstruct historical conditions.

The two principal issues that will have to be addressed in reconstructing the fate and transport of contaminants in the water distribution system are well dispatch and simulating the interconnection with the Holcomb Boulevard system, which I address below.

2. Complexities and Modeling Methods

Expected complexities

I think the largest complexity that influences both groundwater fate and transport and water distribution is reconstructing the dispatch of individual wells. This is addressed in *Well Capacity and Use History*. ATSDR has data from 1998 through 2008 for operation of individual wells. It is not clear how much information about historical operations can be gained from current operations. ATSDR should attempt to understand or reconstruct the operating objectives and practices for the pre-1985 period. For example, operating cost is often an important factor in well dispatch. Perhaps a routine policy of rotation of wells was practiced or aesthetic factors might have played a role. Uncertainty in well dispatch may have to be addressed in an uncertainty analysis or sensitivity analysis.

Another complexity will be representing the interconnection of the Holcomb Boulevard and Hadnot Point systems, which I address below.

Recommended modeling methods.

ATSDR should not report mean concentrations, but should instead state concentrations in probabilistic terms.

3. Calibration of contaminant fate and transport model

Changes to calibration strategy.

I am not a groundwater modeler and not an expert in hydrogeology. My observations should be considered in that light.

Comparison of Figure 4 in *Groundwater-Flow Fate and Transport Models* (Tab 6) with Attachment 6 to *ATSDR response to DON letter of June 19, 2008* indicates to me that the groundwater model developed for Tarawa Terrace captured more of the variability of groundwater heads than does the Hadnot Point model. Simulated heads in Figure 4 seem relatively insensitive to observed heads. Similarly, comparison of Figure 1 and Figure 3 of *Groundwater-Flow Fate and Transport Models* indicate to me that the Hadnot point model does not capture the steep gradients evident in the potentiometric surface estimated from observed data but instead generates a more idealized surface.

4. Interconnection of Holcomb Boulevard and Hadnot Point systems.

The materials provided to me indicate that ATSDR has already developed a water distribution network model of the Holcomb Boulevard and Hadnot Point systems and has used this model to make initial evaluations of the impact of contamination events arising from interconnection. Since ATSDR has already developed a water distribution model of the two systems, this model should be used to evaluate the effect of interconnection events. Given the nature of the two systems and the interconnection at one point, I think that conventional calibration parameters (pipe friction, valve and booster pump characteristics) will not be important. Getting pipe volumes correct (i.e. getting pipe diameters and lengths correct) will matter.

The information available to me indicates that most of the interconnection events were triggered when high water demands in the Holcomb Boulevard system, particularly at a golf course, exceeded the capacity of the WTP. Aerial photography shows that the existing golf course is at Paradise Point, in the northwest corner of the Holcomb Boulevard service area, beyond the Holcomb Boulevard WTP and the Berkeley Manor Elementary School (where a TCE concentration of more than 1,100 ppb was measured in January 1985). Because of the location of this large water use, it is likely that any contaminated water entering the Holcomb Boulevard system at BP-742 will penetrate well into the Holcomb Boulevard system, and may enter storage tanks. (The Berkeley Manor Elementary School appears to be adjacent to an elevated storage tank [S-830], so the event of January 1985 probably contaminated that tank.) For these reasons it is probably advisable that extended period simulations of the periods of interconnection will be necessary to fully characterize exposures in the Holcomb Boulevard system due to interconnection with the Hadnot Point system.

Because high water demands are probably driven by irrigation use, a model of water demand based on observed weather could be used to estimate the days on which interconnection was required. The same model could be used to estimate water use due to irrigation so as to modify the "normal" spatial and temporal pattern of water use. Because contaminated water very likely found its way into water storage facilities in the Holcomb Boulevard system, and because the concentrations observed during one interconnection event were very high (more than 1,100 ppb of TCE) the duration of exposure due to an interconnection event could extend significantly after the interconnection is closed. Use of a "typical" interconnection scenario would probably not be appropriate.

Mary C. Hill, PhD

In the following, the charge to the panel is in Times New Roman font and my comments are in Arial font. Tarawa Terrace is referred to as TT. Hadnot Point and Holcomb Boulevard are referred to as HP, HB, respectively.

Given the state of the science for reconstructing historical levels of contaminants in drinking water for the purpose of estimating human exposures, do the methods used and proposed by ASTDR provide an adequate level of accuracy and precision?

To address this charge, ATSDR is requesting the expert panel's opinion and views and is seeking oral and written recommendations from the panel. Thus, ATSDR is seeking a majority opinion and opposing views.

1. Based on information provided by ATSDR to the panel, are there modifications or changes that ATSDR should consider making in its approach to quantifying historical concentrations associated with:

    a. Data analysis?

Airline head data

I agree that airline measurements in pumping wells tend to be prone to error. If measurements of this type are available and used for the HP, HB, and vicinity modeling effort, I suggest that they be analyzed and presented in a more distinct manner than appears to be the case for the TT effort. For example, in tables such as those shown in TT chapter C, Appendix C, identify the airline measurements clearly. Even with an explanation elsewhere in the report, clear identification here would be useful. Also, Figure C20 (p. C36) should be divided into two figures so that the fit to the more accurate data is revealed more clearly and the difficulties with the airline data are more apparent.

Consider graphs of the airline data that clearly demonstrate the difficulties so that readers are keenly aware. These graphs might be plots of measurements or implied drawdowns against time or pumping rate. It may be that the airline data are too noisy to be useful. Use the analysis to identify results that could be useful to model calibration. It is possible that no such meaningful results are apparent. If meaningful results are apparent, it may be that some interpretation derived from the measurements would be more meaningful than using the data directly in comparisons with simulated values.

Address obvious patterns on the residuals (which are generally supposed to be random, but see Hill and Tiedeman, 2007, p. 111–113 for exceptions). For example, in figure C20, features such as the band associated with simulated values between 8 and 12 require evaluation and explanation.

Even accurate measurements of heads in wells being pumped are inconsistent with the heads calculated by most numerical models because the model grids are unable to capture the rapidly changing gradients near the well. The basic problem is demonstrated in Figure C21 and I6 (p. C36 of chapter C and p. I19 of chapter I, respectively). Any heads measured in pumping wells should be corrected for grid size effects. This can be done using an analytical solution.

Hydrogeologic foundation

Consider more sophisticate geologic depositional frameworks and use such information in constructing the calibrated hydraulic-conductivity distribution and the realizations used in the uncertainty evaluation. For TT, the hydraulic conductivity variations considered are Gaussian, but it is well known that geologic deposits often are not Gaussian. Coastal plain deposits, for example, have typical non-Gaussian structures that are not mentioned in the TT analysis. There are studies about similar sites that might be useful in developing alternative distributions of hydraulic conductivity. For example, a brief search lead me to Cardinell (1999) and Jean et al. [2004]. Additional investigation is suggested. Consider the method presented by Poeter and McKenna (1995) and the related software MMA (Poeter and Hill, 2007) for generating and analyzing the realizations.

Precipitation data

Data from all 10 measurement locations should be mentioned at least briefly in the study to demonstrate the uncertainty in the precipitation values used.

Is there anything about the contamination considered that is likely to be affected by periods of high precipitation such that a few short simulation representing high recharge events would be advisable? I would expect the answer to this question to be no, but I thought I would ask.

Concentration data

A nice aspect of the available data is that there are repeated measurements over a short time at the same location. This is important information because it reveals the kind of variation that is likely and which a model of the type developed is unable to replicate either in the calibration or the uncertainty analysis. Yet it is not apparent to me that the advantage an challenge of this aspect of the data is considered in a very sophisticated way in the TT study. One challenge of the data is obtaining meaningful calibration targets. In the TT study, all the data are used. One problem with this approach is that because the model is designed to represent basic patterns (as is appropriate given the information available for model construction), it can not possibly match the data variability over time. This confuses the resulting analysis of residuals. The model is set up so it is impossible to match the calibration targets posed and, indeed, it does not match them. It is not clear what is learned by this exercise. An alternative is to develop a conceptual model about what the measurements mean and interpret the data and include it in model development accordingly. For example, can such a high value only exist in the presence of pervasive contamination so that the existence of any value that high is important? If so, this might lead to a calibration that includes as observations only the highest values measured at each site. Alternatively, if the kind of variability displayed is interpreted to mean that the water concentrations are likely to be of varying proportionally to the measured samples, and time-averaged value might be used for the observation. This kind of hypothesis testing can be thought of as an example of producing alternative models. However, instead of stochastic realizations, the realizations are deterministic and based of different conceptualizations of different aspects of model development. Such an approach requires an objective method of model calibration, such as can be achieved using optimization methods. The modified Gauss-Newton method is a popular alternative. Objective calibration methods are discussed further in later comments.

Data and model error

There is considerable confusion in the TT study about how data and model errors are handled. There is the a priori calibration criteria, the heads with very different error characteristics, and the

concentrations with variability that clearly can not be simulated with the model as constructed. It would be useful for the HB, HP and vicinity study if a comprehensive approach to data and model error could be adopted. The most important step is to address issues related to the model being an average representation of the system while the data are not. This is not necessarily a problem for the purpose of this model because health outcomes are likely related to extended exposures and a model that represents average conditions is likely to perform that purpose well. The problem comes in when measured data is used to test the validity of the model. The problem is, in my opinion, made worse by the ad hoc calibration methods used. Such ad hoc methods make hypothesis testing impossible. With an objective calibration method that uses optimization, one can, for example, investigate the consequences of different interpretations of the calibration data. Some ideas on using optimization for model calibration and coping with measurement and model errors presented by Hill and Tiedeman [2007] could be useful. UCODE_2005 includes a mechanism for handling non-detect observations.

b. Groundwater flow and contaminant fate and transport?

My comments about simulating flow and contaminant transport are included under item 2.

c. Distribution of drinking water?

As noted below, this is not a field of expertise for me and I defer to those who specialize in this topic.

If, in the panel's majority opinion, ATSDR should consider changes in its approach, what specific changes does the panel suggest?

Please see my suggestions above.

Simulated water budgets

Tables C11 and C12 show global model budgets for TT for December 1984 and values from the steady-state budget are mentioned in the text. In the HP, HB, and vicinity report it would be nice if the comparison of key numbers was provided in a separate table. It would also be of interest to possibly provide additional information about the flow field. For example, simulated contributing areas to major pumping under selected pumping scenarios well may be useful.

2. ATSDR has provided panel members with summaries of information, data, and preliminary analyses that will be used for reconstructing historical contamination concentrations at Hadnot Point, Holcomb Boulevard, and vicinity.

   a. What data analysis and modeling complexities do panel members anticipate and what are their concerns?

The existence of so many plumes is challenging and provides some interesting opportunities. Some sites are well characterized (such as site 78), others have very little data. Transport is sensitive to site-specific conditions, and for some sites very little is known. To help understand the error involved in simulating sites for which little is known, consider simulations in which the model is calibrated using all well characterized sites and reconstruct past concentrations based on that model. Then reduce the data used for one or more sites to the level of the data available for a poorly characterized site. Evaluate the error produced by the lack of data. Consider the error produced given different ways of parameterizing the system. For example, consider a simple parameterization with few estimated parameters that represent only basic features about the system and a more complex parameterization based on geologic structures. Depending on time constraints, possibly also consider a more complex system in which parameters are defined at many pilot points and values are constrained using regularization. Evaluate which approach produces the most accurate predictions for sites with little data.

b. Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations?

It needs to be understood that the quality of the reconstruction depends mostly on the available data. The available data in any study is generally used most advantageously when hypotheses are formulated and tested. Such testing requires objective methods of model development which were not used in the TT study. I encourage the use of a hypothesis-testing framework and objective calibration methods.

Numerical dispersion

The method used to simulate transport is one that has considerable numerical dispersion. This results in a very smooth simulated plume unable to represent potential temporary or local peaks in the contaminant concentrations. While such peaks may not be substantial, a method capable of representing them would allow their effect to be evaluated. Runs with reduced numerical dispersion tend to be computationally demanding. They might be used in a limited number of runs to test specific hypotheses. These hypotheses would likely involve variations in source concentrations, recharge rates, the hydraulic conductivity distribution, and pumping rate. Locally refined grids may be useful to this analysis.

TechFlowMP

The use of the custom-coded computer program TechFlowMP instead of the widely used RT3D is somewhat perplexing. The Davis [2003] reference cited by ATSDR in their reply to DON comments in the 2008/2009 comments and responses uses RT3D to simulate transport of TCE, DCE, and VC. I believe that if RT3D lacks some specific capability needed in this work it could have been modified accordingly. If there is a clear reason to justify the development and use of TechFlowMP, a brief explanation should be added when it is first mentioned and in other relevant reports. This is too important an issue to just mention this justification once.

"Regional model"

Consider the possibility of one "regional model" covering TT, HB,HB, and vicinity and using local refined grids to represent selected situations. This approach encourages consistent representation of hydraulic properties and recharge, and allows flow in deeper model layers to continue beneath Northeast Creek, which may very well actually occur. In this way, it makes the modeling effort more defensible.

Uncertainty analysis

One aspect of the uncertainty analysis that bothers me is that the uncertainty is not smaller in the years in which measurements are available. I assume this is because the concentrations during the reconstruction period have no mechanism by which they could be substantially higher or lower than the values calculated for the 1980's and 1990's. If this is the case, it is very important to consider the aspects of model construction that lead to this result and ensure that they are valid. This would occur, for example, if the source concentration or the mass per unit time of the source is held essentially constant over a long period of time. The same consideration would also apply for any analysis of HP, HB and vicinity.

Log axis on graphs

At the public meeting in November, 2008, one of the speakers expressed suspicion that the log axis on the figure with reconstructed concentrations and the results of the Monte Carlo analysis because of the log axis. As scientists we are very used to log scales, but for the public I wonder if including a figure with an arithmetic axis would be useful.

3. ATSDR established a calibration target of ± ½ order of magnitude for comparing measured and simulated water quality data for the Tarawa Terrace contaminant fate and transport model.

   a. Are there established standards or guidelines in the fate and transport modeling community for determined and applying specific calibration targets? If so, what are those standards or guidelines?

Guidelines

There is no one set of established guidelines, but there has been much effort internationally in pursuit of such guidelines. Existing guidelines were reviewed by Hill et al. [2004]. This publication is provided as a pdf file with this review. Many of the guidelines have much in common, as well as some differences. These are discussed by Hill et al. [2004].

A priori model fit criteria

In the DON review it is noted that the ASTM guidelines mention a priori definition of a model fit criteria. To my knowledge it is not common in practice and is not a practice I would recommend. For the TT model, it seems to me that a priori definition of a model fit criteria lead to unrealistic expectations of model accuracy. While I support many of the statements made in the DON review (even some that ATSDR staff take exception to), I think the groundwater model is useful as it is. There is one main conclusion provided by the analyses conducted thus far that is, I think, critical. This is that it appears that the concentrations measured as of the 1980's are representative of the high concentrations experienced over many years. That is, there is no indication that delivered water had much higher concentrations occurred in the past. This conclusion would not be possible without the groundwater modeling. Possible difficulties with this result were discussed previously in my comments.

   b. If ATSDR should establish different calibration targets for Hadnot Point, Holcomb Boulevard, and vicinity (compared to targets used for the Tarawa Terrace model), what should the calibration targets be?

Calibration targets

In my experience, in steady-state groundwater models it is very common for most head residuals (observed minus simulated values) to be within about 10 percent or a bit more of the total head loss of a steady-state system. This is not a hard rule and I have never seen a thorough analysis, it is just something I have noticed. As well as the size of the residual, where and when the residuals occur in the system is important. For example, non-random distributions such as all positive residuals in a region with an identifiable characteristic such within a model layer, upgradient area, northernmost area, etc, can reveal large-scale misrepresentation of gradients and, therefore, flow. One of the questions in the DON review addressed just such a concern (Though that comment considered, I believe, a head from a pumping well measured, perhaps, using an airline. Problems with those measurements are discussed elsewhere in this comment.). A deficiency in the TT reports is that residuals are not plotted on maps of simulated heads (fig. C7 and C8). The graphs of observed and simulated heads versus time of figures C10 to C17 do not show the observation times. Using dots for the observation instead of a line would be useful.

If, in the panel's opinion, ATSDR should consider changing its calibration target strategy for the Hadnot Point, Holcomb Boulevard, and vicinity contaminant fate and transport model, what specific changes does the panel suggest?
Please see the suggestions in my responses above.

4. ATSDR has been provided with information that Hadnot Point drinking water (contaminated) was periodically transferred to the Holcomb Boulevard water-distribution system (non-contaminated drinking water) during the period 1972–1987 (typically for a few hours during April, May, and/or June). This may require the use of a water-distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.

   a. Because the water transfers occurred intermittently, which water-distribution system modeling approach do panel members recommend as the most sensible and reliable for estimating monthly mean historical concentrations (e.g, simple mixing or an all-pipes model)?

I would think something more sophisticated than simple missing would be desirable, if possible. I am not an expert on these methods and would defer to those who are.

   b. Because continuous descriptions of the date and duration of the water transfers are not available, do panel members recommend simulating the spatial distribution of historical drinking water concentrations solely for a "typical" month (e.g., June) during these years?

This is a reasonable approach.

   c. Given the intermittent supply of contaminated Hadnot Point water to the Holcomb Boulevard water-distribution system, what simulation scenarios do panel members recommend be developed to provide exposure concentrations for use by the epidemiological study?

Holcomb Boulevard

It depends on how the epidemiological study intends to use the results. If the focus is to establish a link between the contamination and health effects, I am not clear that evaluation of HB is needed at this time. Though members of that community can not be considered unexposed, they do appear to be less exposed. As such, they provide a less useful sample with which to demonstrate a link or lack of a link between the contamination and health outcomes. If a link is found for the communities with grater exposure, it seems to me only at that point that the community with less exposure would be considered seriously to have suffered potential adverse health effects. However, I in formulating this opinion I may missing something in the strategy for the epidemiology studies.

5. ATSDR has set a target date of December 2009 for completing historical reconstruction modeling tasks for Hadnot Point, Holcomb Boulevard, and vicinity. If, in the panel's majority opinion, ATSDR should modify the project tasks and schedule, what specific activities does the panel suggest ATSDR modify and how should the project schedule be modified?

Hypothesis testing

This deadline seems ambitious based on my limited understanding of what has been accomplished so far. One alternative would be to maintain the scheduled completion date but modify the deliverables. Especially, simulations oriented toward specific hypotheses relevant to the epidemiological work would be useful. Indeed, it seems to me that developing such hypotheses and using them to focus the groundwater modeling work could prove to be a very useful approach.

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Leonard F. Konikow, PhD

Comments

These preliminary comments focus on the Draft Report for the Expert Panel. Assessing ATSDR's Water-Modeling Analyses Supporting the Current Health Study at U.S. Marine Corps Base Camp Lejeune, North Carolina (Report Title: "Analysis and Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point, Holcomb Boulevard and Vicinity, U.S. Marine Corps Base, Camp Lejeune, North Carolina"). First, comments include responses to the specific charge and questions to the Panel included in Chapter 2 of the Draft Report. These are followed by specific comments addressing or questioning issues and statements in the entirety of the draft report.

CHARGE TO PANEL: … do the data analysis and computational methods provide an adequate level of accuracy and precision?

The approach taken appears to be quite reasonable, as far as can be told from the available information and with exceptions noted or discussed below, but indeed the level of accuracy and precision may still not be adequate because of the paucity of data and complexity of contaminant sources during the time period when the history is to be reconstructed. The adequacy will depend in large part on the reliability and soundness of the groundwater flow and transport models that will be developed (but which have not been adequately described in the reviewed documents). As noted in comments below, the approach used to estimate reaction rates appears to lack a firm theoretical basis for providing confidence in the accuracy and precision of the calculated values.

QUESTIONS FOR THE EXPERT PANEL:

1. … are there modifications or changes that ATSDR should consider making in its approach …?

a. **Data Analysis?** The hydrogeologic framework needs to be defined more accurately than described in this report. This should include development of predevelopment and transient water-table maps; head maps for aquifers being pumped and for those contaminated; three-dimensional views of head gradients and flow vectors, mapping vertical components of groundwater flow; descriptions of well construction details (relative to the stratigraphy) of supply wells; and an analysis of heterogeneity (spatial variability) in hydraulic conductivity of aquifers. Additional detailed comments and concerns are included in the specific comments on the draft report that follow.

b. **Groundwater flow and contaminant fate and transport?** Little was presented about the planned transport modeling, so little could be reviewed. However, I would recommend that the transport modeling be supplemented by the use of MODPATH to analyze particle pathlines, traveltimes, and contributing source areas to contaminated supply wells. These analyses could provide substantial insight to transport mechanisms with little additional effort. The computational cost for running MODPATH is minimal. The results would also provide conceptual cross-checks on the results of the more complex solute-transport modeling. For all modeling, the modeling errors (residuals) need to be analyzed more carefully. The analysts should reconsider the vertical discretization of the uppermost aquifer system, which presently lumps two permeable zones (aquifers) and two confining units into a single model layer.

c. **Distribution of drinking water?** Ascertain the need to define the distribution of drinking water on a much finer time scale than can be defined for the input of contaminants from the supply wells.

What changes in approach, if any, should ATSDR consider?

- I'd suggest that ATSDR consider the use and application of age dating of groundwaters as an alternative and independent method to cross check on estimated breakthroughs and travel times as computed by the fate and transport models. This would involve collection of water samples from several key wells and analyzing them in the lab to estimate the content of several environmental tracers from which an approximate age of the groundwater (and fraction of "young" water) can be estimated. Although there are uncertainties and errors associated with doing this, it can provide an independent supplemental approach to gaining insight into groundwater flow and transport and is being applied more frequently in groundwater studies around the world. The costs of a preliminary age study would probably be substantially less than the cost of the Expert Review Panel. Consultation with experts in age dating of groundwater is suggested as a preliminary step.
- The accuracy of estimates of porosity are critical for estimating the mass of contaminants initially in the groundwater system and also for the fate and transport model. More focus is needed on these estimates and on distinguishing between effective and total porosity. If no data are available on porosity values in this study area, I'd suggest that (1) literature searches be conducted for data on these same hydrogeologic units in other areas along the Atlantic Coastal Plain, and (2) some undisturbed cores be collected in the study area so that porosity can be directly measured in a number of such samples.

2. … reconstructing historical contaminant concentrations …

a. **anticipated data analysis and modeling complexities …?** Overall, the task at hand is an enormously difficult and challenging one, and there are numerous difficulties confronting a successful completion. There are numerous sources of uncertainty both in the data analysis and the modeling results. Attempts should be made throughout the course of the project to quantify, as well as possible, the degree of uncertainty in each stage of the work. In the transport modeling, the issue of estimating the appropriate magnitude of the dispersivity coefficients is a difficult one for which there is no simple answer or standard. This will certainly be clouded by the use of the finite-difference solution method in the MT3D transport model, and the effects of numerical dispersion on calculated early arrivals and breakthroughs, as well as on peak concentrations, must be carefully considered and evaluated, and alternative solution methods or discretizations considered.

b. **Which modeling methods do panel members recommend ATSDR use for reliable monthly mean concentration results for exposure calculations?** The proposed modeling methods appear to be quite reasonable and appropriate to the task, although given the complexity and uncertainty in the underlying data base, there is no guarantee about the accuracy and reliability of the results; those will need to be assessed as the work progresses. Within the broad framework of using MODFLOW and MT3D, details of the approach and implementation must be carefully evaluated, and alternatives considered, to assure the maximum chance of achieving reliable results.

3. … calibration target of ±½ order of magnitude for water-quality data for fate and transport model

a. **Are there established standards for establishing specific calibration targets? If so, what are they?** Overall, there are no standards and probably should not be any. Such targets are inevitably arbitrary and to some extent meaningless. They tend to distract from the quality of the calibration process and shift focus to the arbitrary goal. It is a "red herring." Not achieving a predetermined calibration target should not disqualify a model, nor does that prove a model is not valuable or useful. Conversely, meeting such a predetermined calibration target does not prove that the model is a good one or that it meets the needs of the particular study or that its calculations and predictions are accurate and/or reliable.

b. **Should ATSDR establish different calibration targets than for the Tarawa Terrace model?** In my opinion, the use of specific calibration targets should be abandoned. They have no real value in the context of hydrogeology, and can only serve to provide a false or meaningless image of the quality of the developed model. ATSDR only has a limited time to complete the study, and you will do the best job possible within that limited time and budget. Applying a calibration target will not lead to a better model, but it will cause some time to be spent on comparing the results to the target, and perhaps forcing the results to fall within the target. It would be better to include on-going independent expert peer review during the model development process, as this will have a much higher payoff than calibration targets in terms of improving the quality of the final product.

What specific changes, if any, should ATSDR consider in its calibration target strategy …?

- I repeat the above suggestion: **abandon the use of specific calibration targets** for the reasons given in the above two discussion points.

4. … ATSDR may need to use a water-distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.

a. **Because water transfers occurred intermittently, which modeling approach is recommended for estimating monthly mean historical concentrations?** This is a reasonable question, but one which should answered after some numerical experimentation is completed by ATSDR. Overall, I suspect that less uncertainty will be introduced into the final results by the choice of a water-distribution model than by the uncertainties in the fate and transport model results. I suggest applying several different modeling options to one or two representative monthly periods for which representative or typical input data are available or can be estimated or assumed, and then see if the different distribution modeling approaches yield substantially different answers and, if so, why. Then make the judgment and decision.

b. **Because continuous descriptions of water transfers are not available, should distributions be simulated instead for just "typical" months?** This is problematic because you are no longer "reconstructing" history, but rather computing what the "history" might have been if unknown transfers had been made. How does this uncertainty transfer into the epidemiological studies? It's not clear to me whether the HPWTP is believed to represent the main source of contaminants to the Holcomb Boulevard distribution system. Isn't some contamination present in the Holcomb Boulevard supply wells?

c. **Given the intermittent supply of contaminated HP water to the HB water-distribution system, what simulation scenarios are recommended to provide exposure concentrations for use by the epidemiological study?** Perhaps focus on the sources of contamination present in the Holcomb Boulevard supply wells? (I assume this is a source of some contaminants to the HB WTP.) Otherwise, perhaps take a more probabilistic approach, and develop exposure statistics both with and without the cross-connections during months with uncertain connections, and/or compare exposures and health risks for months with known cross-connections to months without any HP water entering the HB WTP.

5. … ATSDR has set a target date of Dec. 2009 for completing historical reconstruction modeling tasks … What specific activities, if any, should ATSDR modify and how should the project schedule be modified?

a. Since the December 2009 deadline apparently includes completion of the model development, analysis of the modeling results, assessment of uncertainties, and completion of a report describing the work, this deadline represents a very ambitious schedule (especially since at the time of preparation of this review, in April 2009, the results of the transient groundwater flow model are not yet available). On-time completion can be accomplished if sufficient experienced personnel are contributing to the effort. I believe the transport modeling efforts should be supplemented with MODPATH analyses, which might extend the schedule by several weeks or a month. I also believe all modeling efforts would benefit from an intermediate peer review of work in progress; preparation, conducting, and responding to an expert peer review might add 2 to 3 weeks to the schedule, but would certainly be worthwhile.

Specific and Detailed Review Comments on the Draft Report and Methodology:

Chapter 1, Second Report (Reconstructing Historical Exposures to VOC-Contaminated Drinking Water at U.S. Marine Corps Base Camp Lejeune, North Carolina)

Fig. 4, p. 10: I don't understand what goes on in the pink box labeled: "Fate and transport modeling analyses for historical reconstruction" and whether or not that includes the MODFLOW-PEST-MT3DMS approach that is also shown downstream in the green box.

p. 14, table 3: It would be useful to also show the density of wells, because it is much lower in the Hadnot Point area than in the former study area of Tarawa Terrace (specifically, about 17.4 wells per sq. mile versus 105.7). This may affect the resolution and integrity of the estimated flow fields and contaminant plumes.

Chapter 1, Third Report (Reprint of paper, "Reconstructing Historical Exposures to VOC-Contaminated Drinking Water at a U.S. Military Base" by Maslia et al.)

This is a very nice paper that illustrates the approaches proposed here for the larger Hadnot Point-Holcomb Boulevard study area. However, I have concern about the rapid rise shown in Fig. 3 for well TT-26, where concentrations exceed the MCL in just 4 years time. I think the arrival time may be biased toward a computed arrival earlier than might have actually occurred because of numerical dispersion arising from the use of finite-difference methods in the MT3D model. Because the same modeling technology is proposed for this new study, and the calculated arrival times at these very low

concentrations appears to be an important factor in the health and exposure studies, I think this issue has to be addressed and evaluated carefully.

Chapter 3 (timeline)

There apparently is no task or activity listed for development of the hydrogeologic framework (analogous to Chapter B report for the Tarawa Terrace study). That study covered the Tarawa Terrace and much of the Holcomb Boulevard areas, but generally did not extend into the Hadnot Point area or other contiguous adjacent areas that might be relevant to the groundwater flow model study. Because the previous 2007 report did not fully cover the present study area, I think this task or activity needs to be confirmed. Such coverage is not only critical for model development, it is also needed for conducting a critical review of the model development work.

Chapter 4 (First Section: Chapter C: Occurrence of Contaminants in Soil and Groundwater)

p. 20: The statement that vinyl chloride indicates "that PCE &/or TCE degradation pathways were substantially complete within the volume of aquifers influenced by pumping at these wells" seems ambiguous in one regard and unsubstantiated in another. Specifically, the presence of VC in high concentration in HP-602 does indicate that some degradation has advanced to that stage, but the degradation is certainly not substantially completed because very high concentrations of PCE and TCE still remain in the same water samples from HP-602. VC is generally absent from most other analyses reported in Table C7, so what does that say about the general progress of the degradation? Also, in a confined aquifer, a very large volume of aquifer is influenced by pumping—with effects going out distances of perhaps several miles. There is no basis that I see in these data to infer or conclude that degradation is substantially completed within that large volume of aquifer.

p. 14–22, Background & Environmental History: This section, together with the Installation Restoration Site Histories section (p. 23–70), tells a story of a very complex history of multiple sources of contamination—much more complex than at Tarawa Terrace. It's noted that there's a paucity of data, and that "incidents of contamination within the water distribution networks probably occurred routinely, as well. The major objective of this historical reconstruction is to simulate such incidents of distribution network contamination as accurately and reasonably as possible." In light of the paucity of data and the complexity of the contaminant source history, I wonder if it is possible to accomplish the stated objective with **reasonable** accuracy in a scientifically defensible manner with a strictly deterministic modeling approach.

p. 23, Geohydrologic Framework: This section refers us to Chapter B (Faye, 2008a), but that critical report is not made available to the reviewers. The lack of this report precludes a comprehensive review and a cross-check of critical details about the aquifer system and how they are represented in the flow and transport models. Without this information, the Panel's review cannot be considered to be comprehensive and complete.

p. 35: Semantics: In the discussion of BTEX at site 6, the point is made that BTEX is an LNAPL, yet detected in a deep well, and that this indicates that downward vertical migration was largely by advection. But the migration was not as a NAPL, but rather as dissolved constituents in which the fluid density is essentially unaffected by the presence of soluble components of BTEX, so the fact that the pure phase is an LNAPL seems irrelevant. Furthermore, the migration of most contaminants is probably mostly by advection, so not sure why the distinction is made here.

p. 64, IR site 88: This discussion indicates that the clay layer (equivalent to the Brewster Boulevard upper confining unit) "is a competent aquitard, preventing further downward migration of DNAPLs." This raises two questions. (1) Would it prevent downward migration of dissolved constituents also? (Probably not, if the flow is downward.) (2) If this clay layer is so important, how can it be justified to not represent it explicitly in the flow and transport models? (That is, later discussions indicate that it is simply lumped together with the Brewster Boulevard aquifers and its lower confining unit.)

p. 65: This discussion indicates that a 40-day tracer test was conducted at site 88. Did the test yield any estimates of velocities, dispersivities, or effective porosities that would be useful in constructing the transport model? I would think so, and this should be explored, if it hasn't already been done.

Chapter 4 (Second Section: Well Capacity and Use History for the Epidemiological Study . . .)

p. 3: Indicating that well HP-633 had a capacity of 205 gpm in Jan 1999 probably imparts more precision and accuracy than can be justified. For example, looking at Table 1 and knowing how well yields vary over short time periods, I would infer that the uncertainty here is on the order of ±20% or so. Also, if the gallons pumped in a month are known, what's the point of then computing the adjusted capacity for the month (and same comment for Table 2)?

p. 5, table 1: Is there a difference between "well capacity" and assumed discharge rate? Wouldn't Q vary with time and head? Are the supply wells open to just a single aquifer or to multiple aquifers? If the latter, will the flow model use the MNW Package? Many wells have "well capacity tests" indicated. Do these data yield a specific capacity value that can be used to estimate transmissivity, which can then be used to help estimate spatial patterns of T or K?

Overall: This section does not provide a comprehensive description of well use in the study area as it only provides an example for a single well. This is insufficient to provide a basis for a review of the contributions of the water supply wells to the water treatment plants. Is a more comprehensive assessment under preparation?

Chapter 4 (Third Section: Contaminant Data Summary and Mass Computations)

p. 2 & Fig. 6: The discussion implies that the mass will be estimated for 4 areas. It's not clear if this is an initial estimate and other areas will be estimated later, or if this is the final estimate. Clarification is needed, because even though these 4 areas contribute the greatest mass of contaminants, other areas may also be critical for contaminants reaching some of the supply wells.

p. 4, mass calculations: It indicates that the average concentration was multiplied by the estimated thickness (and porosity), whereby table 3 indicates that only a single "average" value for thickness of the aquifer was used. For the case of the Upper Castle Hayne aquifer, the average is 22 ft, but the data show that it ranges from 20 to 70 ft—a pretty wide range—so that using an average value everywhere can lead to a large error in the estimated mass. But data probably exist on spatial variations in thickness, so why not take a more accurate approach and multiply the concentration at each grid point by the thickness at that grid point? For example, for the plume shown in fig. 9, is the small area with the peak concentrations located in an area of average thickness or not?

p. 5 and fig. 8: It states that "two distinct zones of contaminant data" exist. But is this just an artifact of sampling locations? Were any samples collected from the vertical interval between these two aquifer zones—that is, from the confining units? If not, how is it known there are no contaminants present? Also, how would contaminants get into the deeper aquifer without being transported through the overlying confining unit (and where there should then still be some residual contaminants)? Also, why are there differences between data points shown in fig. 4 and fig. 8 for TCE concentrations with depth in the landfill area. Fig. 4 seems to show detects at intermediate depths that are indicated in fig. 8 to be free of contaminants. The statement that two distinct zones exist is not supported by the data in fig. 4.

p. 6, TCE mass calculation: It appears that a porosity value of 0.2 was used. Does this represent an effective porosity or total porosity? It can make a difference. In previous Tarawa Terrace study, the value of 0.2 was indicated to represent the effective porosity. For purposes of computing the total mass of contaminants, the total porosity should be used. Are there any data available that provide porosity values. If not, I'd suggest that some cores be collected and porosity measured. Also, since the estimate of porosity is only good to one or two significant figures, how can calculating and presenting the TCE mass to 4 significant figures be justified?

p. 17, table 1: The maximum value of PCE is about at the solubility limit. Does this indicate that free phase is still present at or near this sampling location?

p. 17, table 1: A number of values are given to 5 significant figures! This level of precision is unwarranted, unjustified, meaningless, and misleading.

Table 3: Where's the 22 ft thickness for the UCHRBU come from? It's strange that the other three locations all show thicknesses of 32 to 34 ft, while the landfill area shows a smaller thickness of 22 ft in light of the contours on figure B14 of Faye (2007; Chapter B report), where simple extrapolation of the closest contours to the landfill area indicate that the thickness there should be close to 32 ft also.

Table 4: The symbol "J" is placed after some values, but its meaning is not defined.

Table 5: Again, the aquifer thickness is shown as = 22 ft, and fig. 8 and table 3 are cited. However, on fig. 8 it states that the "brackets indicate contaminant data used in the illustration of TCE mass computation in this report," and the brackets encompass about 50 ft of thickness. This apparent discrepancy needs to be explained and clarified. Also, it's indicated that porosity = 0.2, but it doesn't indicate whether it is effective or total porosity. Finally, the calculated TCE mass is presented with SEVEN significant figures here! That does not reflect the accuracy or precision of the estimate and is not justified.

Chapter 5 (Physical and chemical properties and biological transformation of chlorinated volatile organic compounds and BTEX)

p. 18, table 5: Some of the terms in this table are not defined (e.g., K_s and K_{max}).

p. 24, table 7: The heading for the third column is inconsistent (that is, "R^2" does not match "Root mean square"; they are not the same thing). The actual meaning of the values in column 3 must be clarified. Suggest giving units or dimensions also. If R^2 is really a coefficient of determination, then some of the values are very low and the fit explains only a small part of the observed variation.

Section 4.3, p. 22–23: Suggest giving the analytical solution used for the fitting process, and clarifying whether the fitting was done in linear or log space. This could make a difference in the statistical analysis of the fit and the possible generation of bias. Are the conditions at sites 82 and 6 aerobic or anaerobic? Not much (if anything) is presented about the geochemical conditions in the subsurface. Because table 7 shows a large variance in rates at these 2 sites, what is the justification for applying the rates from these 2 sites to the numerous other sites (or in fact to the whole region)? Is an average of calculated rates or the most conservative value used? Do the wells listed in table 7 represent all wells (and all estimated reaction rates) for which this analysis was applied, or is it just a sampling? If all, why wasn't it applied to more sampling locations?

Section 4.3, p. 22–23 & Fig. 6: The fitting was done to data observed during the period from 1993 through 2004. During much of this time period, active groundwater remediation activities were undertaken at several sites. Is it clear that the degradation apparently observed at the sites used to estimate degradation rates (fig. 6) were not also influenced by the remediation activities? This needs to be confirmed. I am especially concerned because the wells used for this analysis are also listed in chapter C as being amongst the deep monitoring wells drilled for Installation Restoration activities at Site 6 (Chapter C, p. 33).

Fig. 6 and table 7: Cross-checking the plot for PCE in well 6GW01D, as an example, against the data listed in Table C25, I see that some of the data are not shown in figure 6. Were they excluded for some particular reason? This selective use of data points must be clarified and explained, or else eliminated. For example, the PCE value of 6500 mg/L observed on 7/18/2001 would plot above limits of this graph in Figure 6 and the point would fall far off the "best-fit" line. Are there similar exclusions of data in the other plots? This seems very questionable.

Summary, p. 24–25: Although I note that the computed rates shown in table 7 are in the "ballpark" of literature values reported in the literature for other sites (table 5), it's a pretty big ballpark. I think this analysis reflects a large degree of circular reasoning, in that it first recognizes that advection, dispersion, and other processes affect concentrations, then assumes that all these processes are negligible in order to estimate reaction rates, then concludes that these rates can be used as appropriate reaction rates in numerical simulation models that include all the other processes. I do not see sufficient evidence that the reaction rates computed in this chapter are adequate or accurate enough to apply in the solute-transport models. Perhaps the reaction rates should also be treated as parameters to be estimated using PEST in the transport model analyses.

Chapter 6 (First section: Reconstructing Contaminant Histories Using Linear Control Model Theory)

p. 6: It states that before 1994, "… there are no contaminant concentration records." However, the Chapter C report (first section of Chapter 4) and its tables of data indicate that data do exist before 1994. Why the discrepancy?

Fig. 2: Does t_a correspond to 1994? Why not clarify and be more specific.

p. 8: The authors assume or conclude that "groundwater contaminant transport may be approximately described by a linear system" in eq. 1. However, the basis or justification presented for this "leap of faith" seems inadequate and it appears to hinge on a black-box model of the groundwater system and apparently does not incorporate the known physics of flow and transport, nor assure a chemical mass

balance. I am not convinced that the limited observations of concentration during the period of no pumping (fig. 2) provide an adequate response history for back-extrapolating of concentrations during the pumping period when no concentration observations are available.

p. 19: The authors say that "the observed and recovered concentrations at the nodes are almost identical." However, there were no observations. They are comparing their estimated (reconstructed) values to simulated values for which in fact were known before the calculations were made. This match, while very nice, is insufficient to support their conclusion that "the matrix A can describe the system behavior of contaminant transport in the groundwater system in the undisturbed environment with reasonably high accuracy." Matrix A is constructed on the basis of the same "observations" that are being "predicted" using Matrix A. So not sure what this proves. But maybe I'm missing something.

p. 22: I'm not convinced that in the health risk assessment that the estimation of peak concentrations is the "most important" factor. What about first arrival at concentrations greater than the MCL, and more importantly, what about cumulative time of exposure to concentrations greater that the MCL.

p. 23, case 2: What's the point of showing a better fit when assuming additional concentration data points exist? Do these additional data actually exist for Hadnot Point and Holcomb Boulevard study areas?

p. 29: The results shown in Fig. 14 are certainly impressive, but I don't have a feeling for how much of the response shown was developed strictly and solely on the basis of observations after stress period 408. Some clarification of this would be very helpful, as it goes directly to the utility of the method for the Hadnot Point and Holcomb Boulevard study areas.

p. 31, Summary & Conclusions: This demonstration was applied to Tarawa Terrace, where the results of detailed deterministic groundwater flow and transport modeling analyses were completed, available, and known, and where there was a single source of contamination with a precisely known location and timing of releases. The Hadnot Point and Holcomb Boulevard study areas are much more complex—with multiple sources and a less-well defined history, and detailed models not yet existing. I remain skeptical about the applicability of the method to Hadnot Point and Holcomb Boulevard study areas.

Chapter 6 (2nd section: Groundwater-Flow and Contaminant Fate & Transport Modeling at Hadnot Point, Holcomb Boulevard, and vicinity, ...)

Overall: This chapter is too sketchy and short of details to allow a comprehensive and meaningful review of the planned modeling activities.

p. 2: It says that the predevelopment model will be calibrated to steady conditions using average potentiometric heads. Is this an average over time or in space? Why would an average head during transient development periods with pumpage be representative of predevelopment conditions?

p. 3, para. 1: Combining the 4 known units of the Brewster Boulevard system into one single model layer seems inappropriate (as also shown in table 2). This contains a confining unit that was previously declared as being important to flow and transport, as well as a deeper and thicker second confining unit. Avoiding convergence problems doesn't seem like an acceptable justification. This lumping near the land surface, where contaminants enter the system, seems like it will adversely impact the accuracy and reliability of the transport model by smoothing out the properties of these two low-permeability confining units.

p. 3, end of para. 1: If layer elevation data are available, then it follows that information on thickness variations would be available too. It would have been helpful for this review if maps of layer thicknesses were included in this report.

p. 3, para. 2: It says that boundary conditions are based on the conceptual model, but there is no description of what the conceptual model is or entails. This basic element is needed for a comprehensive review of the adequacy of the modeling.

p. 3, para. 2: It says "a no-flow boundary formed by a topographic divide surrounds the rest of the model." I don't see any evidence of this. Where are the boundaries and where are the divides?

p. 3, para. 2: What's the vertical accuracy of the DEMs? Is the value of 200 ft^2/d arbitrary?

p. 4: Why apply a constant Kh for every layer? Aren't there data available to help define spatial variations in K?

p. 4: A value of Kh = 1 ft/d seems high relative to the Kh in some of the aquifer units.

p. 4: It doesn't seem so important that there are 5413 water-level observations. What's more important is how many locations are there data at, and which of those (and how many of those) reflect predevelopment conditions.

p. 4, para. 2 (model calibration): How many observations were used for the PEST analysis? Also, "estimated observed" is an oxymoron.

p. 4, para. 2 (model calibration): Although the land-surface altitude may be known within 3 ft, how accurately is the elevation of the measuring point known relative to land surface. Is it always accurately documented, or is it an additional source of error?

p. 5: If airline measurements themselves have errors of ± 12 ft, then shouldn't the errors in land-surface elevation and measuring point elevation be added to that?

p. 5, para. 2: Aren't all of the observed water levels subject to some drawdown from adjacent wells during the development period? When was an averaged value used versus a maximum value? Criteria and decisions seem too vague.

p. 5, para. 2: It's not clear what is meant by a cell "getting flooded." There's no "flooding" in MODFLOW. How would decreasing the hydraulic conductivity of layer 1 help reduce the heads in layer 1? Sounds like it should be the other way around.

p. 5, para. 3: Why were the K's for layers 3, 5, 7, and 9 excluded as parameters? Same for the vertical anisotropy? The text references Plate 1, but I can't find it. What is the basis for dividing the area into two recharge zones? The text refers to an objective function, but never defines what that objective function is (and it needs to be defined and discussed).

p. 6, para. 1: It appears that the model results clearly did not meet the predetermined targets. So what then? What was the point of setting targets ahead of time if no action is taken when they're not met? Or is having 57.5% of heads within the criteria good enough? Would 20% have been good enough?

The scattergram (fig. 4) doesn't particularly indicate a good calibration. It is also essential to prepare a map of residuals so that the nature and distribution of errors, as well as any possible bias in the model, can be seen.

p. 6, Conclusions: It states that the predevelopment model was developed and calibrated, and will be used as initial conditions for a transient flow model. However, I don't see evidence that the calibration was good enough to proceed to the next task.

Figure 1: Which aquifer does this head map represent? Where's the model boundary? What are the offshore water level data points? If this map is for the UCH aquifer, how come in areas of overlap with the predevelopment head map shown in Fig. B30 of the Tarawa Terrace study (Chapter B, p. 52, Faye, 2007) there is such large disagreements?

Figure 2, Parameter Estimation Results: What are the units of "error"? What measure of error is being used? It appears that the value of *K* for layers 2, 6, and 10 are about the same, and substantially different from the other units. Is this consistent with lithologic or geologic data or results of pumping tests? Perhaps they should be lumped into one parameter. Layer 4, which I think represents the main aquifer (the Upper Castle Hayne-River Bend Unit), has a value of *K* that is about the same as that for all of the confining layers. How is this possible? This does not seem reasonable to me, and it needs to be explained. If the estimated *K* for model layer 1 is higher than the actual *K* in its confining units, the travel time of contaminants into deeper aquifers will be underestimated.

Figure 3: Is this simulated head map for the same layer shown in Figure 1? Not clear. It doesn't really look like a great match to the heads in figure 1.

p. 12, Table 1: It may not be appropriate to use the same boundary conditions and features from the steady-state predevelopment model for the transient model of the development period, especially if there are any pumping wells near the artificial lateral boundaries of the model. This should be evaluated and reconsidered during the development and calibration of the transient model, and not fixed based solely on the predevelopment model. Are there any pumping wells located outside the model boundary but close to the study area?

General: It's unclear to me if or how PEST will be applied to the solute-transport modeling work. There are more poorly known parameters inherent in the solute-transport model than in the flow model, so application of PEST can be helpful, but the greater number of unknowns may weaken the results. Consider estimating reaction rates with PEST in order to cross-check the rates estimated using the methods in Chapter 5.

Chapter 6 (3rd section: Historical Reconstruction of the Water-Distribution Systems for the Epidemiological Study …)

It seems a bit inconsistent to be analyzing hourly changes in the water distribution system when the source from supply wells are only being simulated on a monthly basis.

Can this water distribution system model be tested against data in tables in Chapter C (for example, table C13 shows TCE data at several different locations and times during January 29–31, 1985; are there any source concentrations that can lead to a match to these data?). Will PEST be used with the water-distribution model?

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Responses to Charge to the Expert Panel

1. *Based on information provided by ATSDR to the panel, are there modifications or changes that ATSDR should consider making in its approach to quantifying historical concentrations associated with:*

   a. *Data analysis?*

   b. *Groundwater flow and contaminant fate and transport?*

   c. *Distribution of drinking water?*

   If, in the panel's majority opinion, ATSDR should consider changes in its approach, what specific changes does the panel suggest?

The uncertainty analyses discussed in Chapter I of the Tarawa Terrace reports largely address the recommendations put forward by the 2005 modeling expert panel. It appears the Monte-Carlo (MC) method helped quantify certain aspects in the uncertainties associated with reconstructing historical PCE concentrations. It is recognized that MC simulations can require enormous computing power, a limitation that oftentimes precludes rigorous probabilistic analyses of complex systems. The ATSDR team showed that a confidence interval for predicted PCE concentrations can be constructed and that measured values fall within this interval. However, no data were presented to demonstrate that the measured **water levels** are within the MC-simulated intervals. If uncertainty in the hydrologic parameters and inputs is the only cause for the observed gross discrepancies in model-predicted and measured water levels, then it would be expected that the measured water levels fall within the confidence intervals established by the MC simulation, or, in a statistical sense, that the modeled levels are not significantly different from the measured values. If this is not the case, then other, unknown factors have caused the disparities. As has been pointed out in previous communications, there are other considerable uncertainties associated with well pumping that might have caused poor water level simulation and that should be addressed in the reconstruction of historical groundwater flow at the Hadnot Point system:

- The approach used to model well withdrawals on a monthly time step does **not** simulate actual well operations. Wells at Camp Lejeune are not used continuously. They are generally operated on a 12–14 hour basis without being throttled and then turned off. This results in nearly full recovery of head conditions in the production wells on a diurnal cycle. If actual head conditions alternated daily between drawdown and static conditions, the average monthly condition would not be representative of typical conditions, especially if the static regime resulted in flow away from the well field. A cursory analysis using 12-hour time steps could be conducted to assess this impact. This simulation should also account for the fact that the supply wells at Camp Lejeune are operated approximately at design flow.

- A more realistic stochastic simulation of well operation might involve a random selection of a number of wells that operate for a realistic time period (say, 12–16 hours per day) in order to meet daily demand. Depending on the well field capacity, this would leave some wells unutilized for some time (as is currently practiced at Camp Lejeune). The potential impact on uncertainty is easy discernible from the model-simulated PCE concentrations for TT-26 during times when it was off-line. In the larger, more redundant well field at Hadnot Point it is even less probable that any one well would operate uninterrupted for 30 years.

- In the statistical analysis of historical pumping simulation for Tarawa Terrace it was assumed that TT-26 would operate "on average" at 80% capacity or 120 gpm. The remainder of the required monthly production was allocated to the other wells. For stress period 408 (December 1984) for example, the "averaged" TT-26 flow rate would account for 21% of the water production even though this well contributed less than 15% to the well field capacity. By back-calculating it can be concluded that the remaining wells operated on average at less than 50% of their rated capacity. This approach has exaggerated the influence of TT-26 in December 1984 and may have also biased its effect in other years. Therefore, if the well production is averaged over monthly stress periods (which is not recommended), it must correctly account for the relative influence of each well in service for each period. This could be achieved by scaling the mean production of TT-26 in proportion to its capacity relative to the total monthly production.

For Tarawa Terrace, the ATSDR team has addressed distribution system water quality predictions in an efficient, yet realistic way by utilizing a simple mixing approach. Unless the effect of interconnections between the Hadnot Point and Holcomb Boulevard systems are deemed significant enough to impact long-term water quality (see discussion below), the simple mixing approach should also be used in the present study.

2. *ATSDR has provided panel members with summaries of information, data, and preliminary analyses that will be used for reconstructing historical contaminant concentrations at Hadnot Point, Holcomb Boulevard and vicinity.*

    a. *What data analysis and modeling complexities do panel members anticipate and what are their concerns?*

    b. *Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations?*

Multiple sources and contaminants associated with a much larger model domain will likely make reconstruction of the Hadnot Point and Holcomb Boulevard system more complex than Tarawa Terrace. On the basis of the experience with Tarawa Terrace, it is not likely that a deterministic approach will provide satisfactory results. Therefore, a probabilistic approach is recommended from the onset. That is, the uncertainties in flows and water levels should be determined before proceeding with contaminant transport modeling.

In addition, as previously pointed out, groundwater flow modeling should account for actual operational practice. The method of using a monthly average as suggested in the March 2009 document "Well Capacity and Use History" does not represent realistic conditions.

One additional complication for simulating contaminant exposure is the fact that considerable removal of volatile organic compounds might have occurred in the Hadnot Point Water Treatment Plant. The plant, which was constructed in the 1940s, uses a lime-softening process. To adjust the pH downstream of the catalytic softening units, water was passed through a rectangular basin to with carbon dioxide was injected, which is a common practice for softening plants. The re-carbonation basin operation was discontinued at some (unknown) point of time in the past. Whereas VOC removal from other unit processes at the plant was incidental and probably minor, substantial removal (> 90%) might have occurred in the re-carbonation basin. As with an aeration process, the gas injection creates substantial turbulence and mixing and can facilitate partitioning and removal of the contaminants from the liquid phase. Therefore, it is recommended that research be conducted to determine when the re-carbonation was operated, under which conditions (gas flow rate, etc.) and what the likely rate of VOC removal was.

3. *ATSDR established a calibration target of ± ½ order of magnitude for comparing measured and simulated water-quality data for the Tarawa Terrace contaminant fate and transport model.*

   a. *Are there established standards or guidelines in the fate and transport modeling community for determining and applying specific calibration targets? If so, what are those standards or guidelines?*

   b. *If ATSDR should establish different calibration targets for Hadnot Point, Holcomb Boulevard and vicinity (compared to targets used for the Tarawa Terrace model), what should the calibration targets be?*

If, in the panel's majority opinion, ATSDR should consider changing its calibration target strategy for the Hadnot Point, Holcomb Boulevard and vicinity contaminant fate and transport model, what specific changes does the panel suggest?

The accuracy of the model should be prescribed by the intended purpose, i.e., for the purpose of epidemiological studies. A calibration target of ± ½ order of magnitude might be appropriate in a deterministic model if the corresponding resolution in concentration allows determining threshold levels for adverse outcomes. However, if a probabilistic approach is chosen then assigning a calibration target is moot because the level of confidence in the predicted concentrations will provide a direct measure of model accuracy.

4. *ATSDR has been provided with information that Hadnot Point drinking water (contaminated) was periodically transferred to the Holcomb Boulevard water–distribution system (non-contaminated drinking water) during the period 1972–1987 (typically for a few hours during April, May and/or June). This may require the use of a water-distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.*

   a. *Because the water transfers occurred intermittently, which water-distribution system modeling approach do panel members recommend as the most sensible and reliable for estimating monthly mean historical concentrations (e.g., simple mixing or an all-pipes model)?*

   b. *Because continuous descriptions of the date and duration of the water transfers are not available, do panel members recommend simulating the spatial distribution of historical drinking water concentrations solely for a "typical" month (e.g., June) during these years?*

   c. *Given the intermittent supply of contaminated Hadnot Point water to the Holcomb Boulevard water-distribution system, what simulation scenarios do panel members recommend be developed to provide exposure concentrations for use by the epidemiological study?*

Whether simple mixing or an all-pipes model is chosen is dependent on the duration and frequency of the interconnections and the contaminant concentration at the time of interconnection. Consideration must also be given to the system hydraulics, i.e., a 'slug' of contaminated water could be attenuated in water tanks and large mains.

Considerable difficulty will be encountered in quantifying exposures due to contamination arising from short-term (hours to days) interconnections because there will be substantial uncertainty about the source contaminant levels at the time of interconnection. Unless well utilization data are available for the times when the two systems were connected it will be virtually impossible to reconstruct the contaminant mass that entered the Holcomb Boulevard system. It seems that best- and worst-case scenarios (e.g., "clean" versus contaminated wells in service) could be evaluated but they would probably be of little value for epidemiological studies. If the contaminant concentration at the time of a short-term interconnection could be **reliably** predicted, an all-pipes model would be required to estimate exposure in the downstream system.

For interconnections spanning several weeks or months, an all-pipes model would only be useful if the Holcomb Boulevard water plant was online at the same time. In this case, only portions of the service area would receive contaminated water. The extent of the affected area would have to be estimated using an all-pipes hydraulic model.

If the use of an all-pipes model becomes necessary, a probabilistic approach should be used to estimate exposure. That is, all inputs in the model should be based on appropriate probability density functions. Demand allocations should be derived from typical means and standard deviations for a given type of occupancy. The assignment of total system demand, diurnal patterns and operational controls should also follow this methodology. A Monte-Carlo simulation could then be performed to arrive at node-by-node concentration means and confidence intervals. PRPsym appears to be a useful tool for stochastic simulation of water demands.

5. *ATSDR has set a target date of December 2009 for completing historical reconstruction modeling tasks for Hadnot Point, Holcomb Boulevard and vicinity. If, in the panel's majority opinion, ATSDR should modify the project tasks and schedule, what specific activities does the panel suggest ATSDR modify and how should the project schedule be modified?*

Given the increased complexity of this system and the time required for the completion of the Tarawa Terrace modeling effort, it seems that the proposed schedule is very aggressive. Considering that intermediate results might require additional (external) review, it might be justified to delay the completion of the modeling tasks appropriately.

Randall R. Ross, PhD

Please find attached, comments on the *Analysis and Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point and Holcomb Boulevard and Vicinity, U.S. Marine Corps Base, Camp Lejeune, North Carolina and Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions*, Chapters A through J. These documents were reviewed under the following Charge: Given the state of the science for reconstructing historical levels of contaminants in drinking water for the purpose of estimating human exposures, do the data analysis and computational methods used and proposed by ATSDR provide an adequate level of accuracy and precision? Though the charge is specific to proposed work related to the Hadnot Point/Holcomb Boulevard (HPHB) areas, the Tarawa Terrace (TT) reports were also reviewed, since the basic approach and methods used for TT are proposed for application at HPHB, and the proposed methods are not described in sufficient detail in the HPHB documents. The materials have been reviewed by me and Dr. Milovan Beljin, a subcontractor to Shaw, Inc., a technical support contractor to USEPA, whose input is contained herein. If you have any questions regarding these comments, please do not hesitate to contact me at your convenience.

General Comments

The work that has gone into estimating human exposure to simulated contaminant levels in drinking water at TT is impressive. The approach used is sound and scientifically defensible. The TT efforts represent a unique exercise and best-case scenario for success. This is mainly due to the nature of the primary source of contamination (i.e., ABC Cleaners). However, the same cannot necessarily be said for the HPHB area. The contaminant sources for the HPHB area are numerous and more complex than for the TT area.

While previous reviewers commented on general aspects of the Camp Lejeune modeling, there appears to be a general lack of comments specific to input parameter values and model assumptions. As with the TT study, it is anticipated that the flow (Chapter C) and transport (Chapter F) models will serve as a basic foundation for modeling multi-species (Chapter G), effects of groundwater pumping schedule variations (Chapter H), and sensitivity and uncertainties analyses (Chapter I). Lessons learned from the TT modeling can be applied directly to HPHB.

Specific Comments

1. In the vicinity of TT, the nine aquifers and confining units above the Beaufort Formation are represented in the flow model with seven layers (Table C1, p. C7). The top three geohydrologic units (the TT aquifer, the Tarawa Terrace confining unit, and the Upper Castle Hayne aquifer) are included in a single model layer (Layer 1). Figure B9 (p. B18) indicates that the TT aquifer thickness varies from 10 to 30 feet; Figure B12 (p. B22) indicates the thickness of TT Confining Unit varies from 8 to 20 feet; and Figure B14 (p. B14) shows that the thickness of the Upper Castle Hayne aquifer (River Bend Unit) varies from 16 to 45 feet. The isopach maps clearly illustrate that the three top units are continuous within the model domain. There should be an explanation how the three geohydrologic units of different hydraulic properties (i.e., two aquifers and a confining unit) are represented with a single model layer. It appears that the HPHB model was similarly constructed (i.e., the model layer 1 includes confining units).

According to the text "… sediments equivalent to the TT aquifer are generally unsaturated" (p. C6) and "… in the vicinity of the Tarawa Terrace Shopping Center, the TT confining unit is mainly absent" (p. C7). The text contradicts Figure B12 which depicts the TT confining unit as about 17 feet thick in the vicinity of the Shopping Center and the potentiometric map (Figure C5) shows that the water levels are clearly above the top of the top of the TT confining unit (Figure B11).

It is suggested that geologic cross-sections through the model domain with clearly marked geologic units and the model layers be included in subsequent reports.

2. Figures B4 and C4 both show the thickness of the Castle Hayne Formation in the vicinity of the TT. Yet, the two maps show different contour lines without any control points posted. It is suggested that subsequent figures that show contours also post the control points and values used to generate the contours.

3. The oldest and/or highest water-level measurements were selected at 59 locations to estimate the predevelopment potentiometric surface. The data are listed in Table C5 and the potentiometric contours are shown in Figure C5. The data were collected from different aquifers and over a period of over 60 years (i.e., 1941 to 2002). During that period, a number of production wells were active. For example, at least six production wells were active in 1961. So how can water level values from 1961 be representative of the "predevelopment" potentiometric surface? The annual rainfall and the recharge rates over the period varied as well (see Table C7). Creating a "composite" water level map based on the data from different years and different aquifers is not an acceptable practice in the groundwater industry. Although the data are "real" (Figure C5), a groundwater model that can reproduce the composite data set (Figure C7) cannot be considered a calibrated model. There is no evidence that the predevelopment model is representative of long-term, average groundwater flow conditions prior to the development (pumping).

A similar approach was used for stage 1 steady state calibration of predevelopment conditions for the HPHB modeling exercise. As stated, simulation results are required to match estimated observed predevelopment water levels within ±12 ft for supply wells, based on assumed errors associated with airline water level measurement techniques. These points appear to be of very little value toward the modeling effort, given the extremely liberal acceptance criteria (± 12 ft) and should not be used in future exercises. Similarly, simulations results for monitoring wells must match within ±3 feet of estimated observed predevelopment water levels, based upon estimation errors associated with determining monitoring well elevations from topographic maps. It is recommended that all wells included in this and future studies be surveyed and tied to a common datum.

4. The surface of Northeast Creek within the active domain was assigned a specified head of zero in model layer 1, corresponding to sea level (p. C21). However, Figure C6 indicates that the specified head nodes along the eastern model boundary do not coincide with the Northeast Creek and Figure C7 depicts the 2, 5, and 7-foot contours intercepting the surface of Northeast Creek. Either the Northeast Creek is represented incorrectly in Figure C7 or the specified head cells are not placed along the water edge. Since the specified heads will also be used to represent the Creek in the HPHB model, a precise placement of the cells will be required.

5. Figure C6 shows the model grid and model boundaries (assumed to be for model layer 1). It is unclear how the boundary conditions vary among the other layers. The same question applies to the HPHB model. A separate figure (or figures) depicting the boundary condition in deeper layers is needed.

6. Table C7 lists the annual rainfall and effective recharge rates assigned during flow model calibration. The rainfall data are probably the most reliable data available. The annual rainfall

varies from 37.99 inches (1970) to 81.86 inches (1974). Since the total simulation time is divided into stress periods, each one-month long, were the monthly rainfall data considered in order to capture the seasonal changes? Although the HPHB transient model includes even a large number of stress periods, a consideration should be given to vary the recharge rates for each stress period. Besides the recharge derived from the precipitation, were any other sources of recharge present in the HPHB model area (e.g., septic tanks)?

7. At model cells that correspond to the location of water-supply wells ("well cells"), the vertical conductivity of confining units penetrated by the well was increased to 100 ft/day to duplicate the effect of gravel and sand packs used to complete well construction (p. C22). What is the justification for the assumption? Considering that the cell dimensions are 50 feet by 50 feet, the well cells are "windows" in the confining units that allow a relatively significant flow between the model layers.

   It is unclear if the HPHB model will employ a similar approach. If so, it is suggested that this approach be reevaluated.

8. Specific storage values for the TT model layers 2 through 7 were assigned based on an assumed storativity of 0.0004 for each layer, divided by respective cell-by-cell thickness (p. C22). While the model layers 2, 4, and 6 represent confining units, layers 3, 5, and 7 represent aquifers. The specific storage is a function of the water and the aquifer material compressibility. The usual practice (in the absence of the real data) is to assume a specific storage value and multiply by the unit thickness to obtain the storativity.

   It is unclear whether the specific storage values will be derived in a similar manner for the HPHB model. The storage coefficients obtained from the aquifer tests and the information about the geologic material of the HPHB model layers should be considered first.

9. Pumping rates assigned to individual TT water-supply wells were applied to the transient model for 528 stress periods. Each stress period represents a single month beginning January 1951 and ending December 1994 (p. C23). Stress periods were not subdivided into time steps. Accordingly, each stress period equaled 28, 29, 30 or 31 days. The most significant changes in the water levels occur at the beginning of a stress period (after the new pumping or recharge rates were applied). For that reason a stress period is usually divided into time steps, with the first step being the shortest and then increasing progressively from step to step. The length of a time step is also important in a solute transport modeling. The sensitivity of the HPHB model to the temporal discretization (the length of the time steps) should be documented as it was done for the spatial discretization (the cell size) in the TT model.

10. Hydrographs of simulated and observed monthly water levels are shown in Figures C10 to C17. Because the time steps are equal to the stress periods, the simulated heads cannot be compared to the observed water levels measured at a specific date. Secondly, the simulated heads represent the **average** hydraulic head for the well cell and not the head in the well itself. Furthermore, due to the well inefficiency an additional drawdown in the production well will occur. Water levels from the pumping wells should be considered suspect and their use is not recommended for creating water level maps nor should they be used for a model calibration.

11. The paper titled "Reconstructing Historical Exposures to Volatile Organic Compound-Contaminated Drinking Water at a U.S. Military Base" by Maslia and others, included in the review package, provides an excellent overview of the extensive effort that has been put forth to predict the impact of the fate and transport of contaminants of concern at Camp Lejeune. Table 4 contains the statistics for the calibrated values for input parameters used in a probabilistic analysis

of modeling results. These values are the end result of extensive model calibration. It is noted that the calibrated value for bulk density (ρ_b) is 2.72 gm/cm^3. This value appears to have originated from the specific gravity of solids (2.72 gm/cm^3) from Morris and Johnson (1967), cited by Faye (2008). This value was incorrectly used as the bulk density input parameter (following a conversion of units), as required by MT3DMS (Faye, 2008).

The significance of using an incorrect value for bulk density in fate and transport modeling relates to how the model calculates the retardation factor (R) of a compound:

$$R = 1 + \frac{\rho_b K_d}{\eta}$$

where *Kd* is the distribution coefficient and η is porosity. A ρ_b value in the range of 1.65 gm/cm^3 would be expected, rather than 2.72 gm/cm^3. The end result of using an unrealistically high value for ρ_b would be higher retardation values, which would translate into longer travel times for contaminants of concern.

12. A biodegradation rate of 5×10^{-4} per day was used to model PCE degradation at Tarawa Terrace. This value was calculated based on observed PCE concentrations in water supply well TT-26 over a 2,151 day period. This method is limited by significant assumptions, including 1) changes in concentration are due only to biodegradation, 2) abiotic processes such as dispersion and dilution are insignificant, 3) flow paths between the source and well are unaltered over time, 4) and the plume is at steady-state. These assumptions usually restrict application of this method to monitoring wells along a discrete flow path, rather than production wells screened over large intervals. Considering that the flow field is changing and the plume is moving due to advection and dispersion, the changes in the concentration at a point cannot be attributed solely to biodegradation.

13. Data to support the case for extensive biodegradation of PCE throughout the aquifer has not been adequately presented. The presence of daughter products (e.g., TCE, 1-2 cDCE and 1-2 tDCE) indicates that degradation is occurring. On January 16, 1985, the reported concentrations of PCE, TCE, DCE, and vinyl chloride (VC) at TT-26 were 1,580, 57, 92, and 27 μg/L, respectively (p. F24). It is unclear if VC was detected in other wells. Tables F2 and F5 do not list the VC concentrations.

14. Mass loading rate for PCE of 1,200 g/d was assigned to a single model cell (layer 1, row 47, column 170) during the period January 1953–December 1984 (p. F25). The mass loading was assumed to be constant and continuous over the period. Is the assumption reasonable, considering the population changes, and thus, the dry cleaning activities, over the period?

15. Figures F21, F24, and F25 depict the potentiometric levels in model layers 1, 3, and 5, respectively, during December 1984. The water levels in the three layers look identical though the open screen intervals for different production wells are located in different layers. Are the contours correct? Without a vertical hydraulic gradient, what is the mechanism for the vertical migration of the contaminants? The vertical migration of the contaminants at the location of the production wells due to the higher hydraulic conductivity within the well cells is evident in the figures.

16. According to the text "…the cell dimensions (50 ft by 50 ft) determine the scale of investigation and the approximate order of magnitude of longitudinal dispersivity" (p. F26). This statement should be removed as the magnitude of dispersivity is irrelevant of the cell dimensions. The dispersivity is considered scale-dependent due to the heterogeneity of the aquifer material and it is often related to the scale of the plume rather than the cell size. However, the cell size should be selected to match the dispersivity value. The cell size in the HPHB flow model is 150 feet by 150 feet; the HPHB solute transport models should employ a finer grid.

Daniel Wartenberg, PhD

Questions for the Expert Panel

Analysis and Historical Reconstruction of Groundwater Resources and Distribution of Drinking Water at Hadnot Point and Holcomb Boulevard and Vicinity, U.S. Marine Corps Base, Camp Lejeune, North Carolina

BACKGROUND

The Agency for Toxic Substances and Disease Registry (ATSDR) is conducting an epidemiological study of in utero and infant exposure to volatile organic compound (VOC)-contaminated drinking water at U.S. Marine Corps Base Camp Lejeune, North Carolina. Three water-distribution systems have historically supplied drinking water to family housing at the base—Tarawa Terrace, Holcomb Boulevard, and Hadnot Point. Two of the water-distribution systems were contaminated with VOCs. Tarawa Terrace was contaminated mostly with tetrachloroethylene (PCE, maximum measured concentration in drinking water of 215 μg/L) and Hadnot Point was contaminated mostly with trichloroethylene (TCE, maximum measured concentration in drinking water of 1,400 jig/L). For this study to be successful, two factors must be known: (1) the time when water-supply wells first became contaminated with VOCs and (2) the spatial and temporal distribution of the contaminated groundwater within the network of pipelines that distributed finished drinking water to on-base military personnel and their families. To quantify these factors for the Tarawa Terrace base-housing area, ATSDR gathered geohydrologic data, water-supply and contaminant concentration data, and developed calibrated groundwater flow, contaminant fate and transport, and water-distribution system models as part of the historical reconstruction process. ATSDR believes that these models are acceptable and reliable representations of the groundwater flow and water-distribution systems for Tarawa Terrace and vicinity (available on the agency's website at *http://www.atsdr.cdc.gov/sites/lejeune/index.html*).

The Agency is now in the process of using modeling approaches similar to those used at Tarawa Terrace to reconstruct historical contaminant concentrations for the Hadnot Point and Holcomb Boulevard areas of the base.

> *This is a lot of information and complex methodology to read and understand without having the opportunity to discuss it prior to providing comments. So, given that I am not a water modeler, I am providing comments based on my best understanding of what has been done. I hope I am not too far off base in my comments and suggestions.*

1. Based on information provided by ATSDR to the panel, are there modifications or changes that ATSDR should consider making in its approach to quantifying historical concentrations:

   a. **Data analysis?**
   The section on "Contaminant Data Summary and Mass Computations provides detailed information on how data were collected, from what sites, how it was prepared and summarized. It is clear that there both are a large amount of data being summarized and a substantial amount of data missing. Available data were interpolated using commercial software, and default settings. One approach to assess the robustness of the data, and to get some indication of the possible importance of missing data or assumptions used in the analyses is to conduct a limited set of sensitivity analyses. This could be operationalized in

various ways. For example, one could exclude a percentage of the data at random, and rerun analyses, comparing these results with the original results with all of the data. Similarly, one could run Surfer with other options (e.g., not the default semivariogram, a non-linear model, a different grid size), to see how much the results vary. (While I know of Surfer, I do not know settings, nor how sensitive results are to these choices, typically.) Perhaps different software could be used to replicate just a few of the results, to enable one to assess the sensitivity of the results to the particular software used. For samples below the detection limit, the values were set to zero, which may underestimate the true levels. It would be interesting to use other models for addressing non-detects, compare results for: (1) assigning the detection limit to those below detect; (2) assigning some middle values to those data points; and (3) assigning zero to those data points. It is important not to exclude these data point for consideration.

Many of these types of approaches have been used by ATSDR for the fate and transport modeling at Tarawa Terrace and Vicinity, as described in the Feb. 2009 publication we received. I suggest that similar approaches be applied to data analysis as well as the modeling at Hadnot Point, Holcomb Boulevard and Vicinity.

b. **Groundwater flow and contaminant fate and transport?**

ATSDR has developed and implemented sophisticated fate and transport models that should appropriate summaries for use in the epidemiologic studies.

c. **Distribution of drinking water?**

I am comfortable with the approaches used for modeling the distribution of the drinking water.

What changes in its approach, if any, should ATSDR consider?

It seems that ATSDR has used a sophisticated approach for this work. My main recommendations are to conduct (or provide results of) some sensitivity analyses so that readers can appreciate the robustness of the results.

2. ATSDR has provided panel members with summaries of information, data, and preliminary analyses that will be used for reconstructing historical contaminant concentrations at Hadnot Point, Holcomb Boulevard, and vicinity.

a. **What data analysis and modeling complexities do panel members anticipate and what are their concerns?**

In any data analysis and modeling activities, there always are concerns about missing data, data inconsistencies, and the adequacy of calibration and prediction. The modelers have done a thorough job so, without getting more involved in the some of the details, it is difficult for me to predict specific problems likely to be encountered.

b. **Which modeling methods do panel members recommend ATSDR use in providing reliable monthly mean concentration results for exposure calculations?**

I need more information to address this.

3. ATSDR established a calibration target of ± ½ order of magnitude for comparing measured and simulated water-quality data for the Tarawa Terrace contaminant fate and transport model.

a. **Are there established standards or guidelines in the fate and transport modeling community for determining and applying specific calibration targets? If so, what are those standards or guidelines?**

This is not my area of expertise (i.e., fate and transport modeling), so I am not familiar with established standards or guidelines.

b. **If ATSDR should establish different calibration targets for the Hadnot Point and Holcomb Boulevard areas (compared to targets used for the Tarawa Terrace model), what should the calibration targets be?**

I am comfortable with ATSDR's approach. What is most important is the relative concentrations rather than the absolute values.

What specific changes, if any, should ATSDR consider its calibration target strategy for the Hadnot Point and Holcomb Boulevard contaminant fate and transport model?

I am comfortable with ATSDR's approach.

4. ATSDR has been provided with information that Hadnot Point drinking water (contaminated) was periodically transferred to the Holcomb Boulevard water-distribution system (non-contaminated drinking water) during the period 1972–1987 (typically for a few hours during April, May, and/or June). This may require the use of a water-distribution system model such as EPANET to quantify the spatial and temporal distribution of historical drinking water concentrations.

a. **Because the water transfers occurred intermittently, which water-distribution system modeling approach do panel members recommend as the most sensible and reliable for estimating monthly mean historical concentrations (e.g., simple mixing, all-pipes model, etc.)?**

I need more information on these models to make a recommendation on this issue.

b. **Because continuous descriptions of the date and duration of the water transfers are not available, do panel members recommend simulating the spatial distribution of historical drinking water concentrations solely for a "typical" month (e.g., June) during these years?**

I recommend considering the spatial distribution for more than one month, to capture seasonal variations.

c. **Given the intermittent supply of contaminated Hadnot Point water to the Holcomb Boulevard water-distribution system, what simulation scenarios do panel members recommend be developed to provide exposure concentrations for use by the epidemiological study?**

I reserve judgment of this issue as it will be better informed when I am able to discuss the exposure issues with the modelers.

5. ATSDR has set a target date of December 2009 for completing historical reconstruction modeling tasks for the Hadnot Point and Holcomb Boulevard areas. What specific activities, if any, does the panel suggest ATSDR modify and how should the project schedule be modified?

In the documents provided, there is only limited information on individual exposure modeling (e.g., water use and consumption). This should be included, both estimates and sensitivity analyses.

Additional comment: It would be helpful to have some discussion of the relevance of this approach for developing data for the epidemiologic study, and alternatives. Further, given the limited number of study subjects in the proposed study, the effort being invested should be qualified by suggesting other uses for the results of the modeling.

Appendix F

Curricula Vitae for Panel Members

Ann Aschengrau, ScD

Education

1975	BA, Biology, Northeastern University, Boston, Massachusetts
1977	SM, Epidemiology, Harvard School of Public Health, Boston, Massachusetts
1987	ScD, Epidemiology, Harvard School of Public Health, Boston, Massachusetts

Work Experience

2003–present	Associate Chairman, Department of Epidemiology, Boston University School of Public Health
2000–present	Professor of Epidemiology, Department of Epidemiology, Boston University School of Public Health
1993–2000	Associate Professor of Epidemiology, Department of Epidemiology and Biostatistics, Boston University School of Public Health
1988–1993	Assistant Professor of Public Health, Department of Epidemiology and Biostatistics, Boston University School of Public Health

Other Experience

2004	Scientific Reviewer, Toxicological Review of Tetrachloroethylene, U.S. Environmental Protection Agency, Washington, DC
2001–2002	Expert Panel Member, Gulf War and Health, Institute of Medicine, Washington, DC
1989–present	Journal Reviewer, American Journal of Public Health, American Journal of Epidemiology, Cancer Causes and Control, Epidemiology Environmental Health Perspectives, Environmental Health: A Global Access Science Source

Memberships

- American Public Health Association, Epidemiology Section
- Society for Epidemiologic Research
- International Society for Environmental Epidemiology

Selected Publications

Aschengrau, A., and Monson, R.R., 1989, Paternal military service in Vietnam and the risk of spontaneous abortion: Journal of Occupational Medicine, v. 31, p. 618–623.

Aschengrau, A., and Monson, R.R., 1990, Paternal military service in Vietnam and the risk of late adverse pregnancy outcomes: American Journal of Public Health, v. 80, p. 1218–1224.

Aschengrau, A., and Seage, G.R., 2008, Essentials of Epidemiology in Public Health, 2nd Edition, Jones and Bartlett Publishers, Inc., Sudbury, Massachusetts.

Aschengrau, A., Ozonoff, D., Paulu, C., Coogan, P., Vezina, R., Heeren, T., and Zhang, Y., 1993, Cancer risk and tetrachloroethyene-contaminated drinking water in Massachusetts: Archives of Environmental Health, v. 48, p. 284–292.

Aschengrau, A., Paulu, C., and Ozonoff, D., 1998, Tetrachloroethyene-contaminated drinking water and the risk of breast cancer: Environmental Health Perspectives, v. 106, no. S4, p. 947–953.

Aschengrau, A., Rogers, S., and Ozonoff, D., 2003, Tetrachloroethylene-contaminated drinking water and the risk of breast cancer: Additional results from Cape Cod, Massachusetts: Environmental Health Perspectives, v. 111, no. 2, p. 167–174.

Aschengrau, A., Weinberg, J., Gallagher, L., Winter, M., Vieira, V., Webster, T., and Ozonoff, D., 2009, Prenatal exposure to tetrachloroethylene-contaminated drinking water and the risk of pregnancy loss: Water Quality, Exposure and Health, DOI 10.1007/s12403-009-0003-x.

Aschengrau, A., Weinberg, J., Rogers, S., Gallagher, L., Winter, M., Vieira, V., Webster, T., and Ozonoff, D., 2008, Prenatal exposure to tetrachloroethylene-contaminated drinking water and the risk of adverse birth outcomes: Environmental Health Perspectives, v. 116, no. 6, p 814–820.

Aschengrau, A., Zierler, S., and Cohen, A., 1989, Quality of community drinking water and the risk of spontaneous abortion: Archives of Environmental Health, v. 44, no. 5, p. 283–290.

Aschengrau, A., Zierler, S., and Cohen, A., 1993, Quality of community drinking water and the occurrence of late adverse pregnancy outcomes: Archives of Environmental Health, v. 48, p. 105–113.

Brody, J.G., Aschengrau, A., McKelvey, W., Rudel, R.A., Swartz, C.H., and Kennedy, T., 2004, Breast cancer risk and historical exposure to pesticides from wide-area applications assessed using GIS: Environmental Health Perspectives, v. 112, p. 889–897.

Brody, J.G., Aschengrau, A., Swartz, C.H., McKelvey, W., and Rudel, R.A., 2006, Breast cancer risk and drinking water contaminated by wastewater: A case-control study: Environmental Health: A Global Access Science Source, v. 5, p. 28.

Janulewicz, P., White, R., Winter, M., Weinberg, J., Gallagher, L., Vieira, V., Webster, T., and Aschengrau, A., 2008, Learning disabilities following prenatal and early postnatal exposure to tetrachloroethylene (PCE)-contaminated drinking water: Neurotoxicology and Teratology, v. 30, p. 175–185.

Ozonoff, D., Aschengrau, A., and Coogan, P., 1994, Cancer in the vicinity of a defense Superfund site in Massachusetts: Toxicology and Industrial Health, v. 10, no. 3, p. 119–141.

Paulu, C., Aschengrau, A., and Ozonoff, D., 1999, Tetrachloroethyene-contaminated drinking water in Massachusetts and the risk of colon-rectum, lung and other cancers: Environmental Health Perspectives, v. 107, p. 265–271.

Spence, L., Aschengrau, A., Gallagher, L., Webster, W., Heeren, T., and Ozonoff, D., 2008, Evaluation of a model for estimating tetrachloroethylene exposure from vinyl-lined asbestos-cement pipes: Environmental Health: A Global Access Science Source, v. 7, no. 1, p. 24.

Vieira, V., Aschengrau, A., and Ozonoff, D., 2005, Impact of tetrachloroethylene-contaminated drinking water in the risk of breast cancer: Using a dose model to assess exposure in a case-control study: Environmental Health: A Global Access Science Source, v. 4, p. 3.

Vieira, V., Webster, T., Aschengrau, A., and Ozonoff, D., 2002, A method for spatial analysis of risk in a population-based case-control study: International Journal of Hygiene and Environmental Health, v. 205, p. 115–120.

Vieira, V., Webster, T., Weinberg, J., and Aschengrau, A., 2008, Spatial-temporal analysis of breast cancer on Upper Cape Cod, Massachusetts: International Journal of Health Geographics, v. 7, no. 1, p. 46.

E. Scott Bair, PhD

Education

1971	Geology Summer Field Camp, University of Illinois
1973	BA, with honors in Geology, College of Wooster, Ohio
1976	MS, Geology, specializing in hydrogeology, Pennsylvania State University
1980	PhD, Geology, specializing in hydrogeology, Pennsylvania State University

Work Experience

1985–present	Ohio State University, Department of Geological Sciences, Columbus, Ohio
1987–present	National Chair: June 1999 to July 2005, Full Professor: 1997; Associate Professor: 1991; Assistant Professor: 1985 [joint appointment, Department of Civil and Environmental Engineering] Ground Water Association, Westerville, Ohio Short-Course Instructor: Principles of Ground Water Flow, Transport, and Remediation; Design and Analysis of Aquifer Tests; Ground Water Control and Construction Dewatering
1986–1999	U.S. Geological Survey-Water Resources Division, Columbus, Ohio; Hydrologist (part-time)
1979–1985	Stone & Webster Engineering Corp., Boston, Massachusetts and Cherry Hill, New Jersey; Geologist, Geotechnical Division

Other Experience

- Geoscience Advisory Board—Building Strong Geoscience Departments, NSF-Division of Undergraduate Education, 2005, Carleton College
- Teaching Hydrogeology in the 21st Century, On the Cutting Edge—Professional Development for Geoscience Faculty, co-leader, NSF-Division of Undergraduate Education, Lincoln, Nebraska, 2005
- Geology and Human Health, On the Cutting Edge—Professional Development for Geoscience Faculty, NSF-Division of Undergraduate Education, Chico Hot Springs, Montana, 2004
- Ohio Hazardous Waste Facility Board, 1993–2003 (appointed by Governors Voinovich and Taft)
- Ohio Geology Advisory Commission, 1990–1997 (appointed by Governors Celeste and Voinovich)
- Oil and Gas Regulatory Review Commission, 1986–1987 (appointed by Governor Celeste)

Professional Societies

- Geological Society of America
- National Ground Water Association
- American Association of Petroleum Geologists
- National Speleological Society

Honors and Awards

- Birdsall-Dreiss Distinguished Lecturer, Geological Society of America, Hydrogeology Division, 2000
- Fellow, Geological Society of America, 1998
- Ohio State University Alumni Distinguished Teaching Award, 1991

Selected Grants and Contracts

2004 National Science Foundation, 'A Civil Action' – Using the Landmark Trial for Learning Environmental Geoscience and the Connection Between Geology and Human Health. Division of Undergraduate Education, Course, Curriculum & Laboratory Improvement, Educational Materials Development, $356,000 (PI)

1999 U.S. DOE, "Hydrologic Testing and Ground Water Flow and Contaminant Transport Modeling of the Roberts-Dawson Mine/FGD Grout Injection Site," U.S. DOE, Pittsburgh, PA, $50,000 (Co-PI)

1994 U.S. Department of Agriculture, "The Ohio Buried Valley Aquifer Management Systems Evaluation Area, Pike County, Ohio," project extension, $400,000 (Co-PI)

1993 U.S. Geological Survey, "Use of Chlorofluorocarbons to Validate Predictive Groundwater Flow Models," $21,000 (PI)

1991 National Science Foundation, "Solute Transport with Convective Instability in Groundwater," $166,109 (Co-PI)

1990 U.S. Department of Agriculture Cooperative State Research Service, "The Ohio Buried Valley Aquifer Management Systems Evaluation Area," $1,600,000 over a five-year period as part of a $6,000,000 interdisciplinary, multi-federal agency project in Pike County, Ohio (Co-PI)

Selected Publications

Bair, E.S., 2001, Models in the courtroom, *in* Anderson, M.G. and Bates, P.D., eds., Model Validation: Perspectives in Hydrological Science, John Wiley & Sons, Ltd., London, p. 57–77.

Bair, E.S., and Lahm, T.D., 1996, Variations in capture-zone geometry of partially penetrating wells in unconfined aquifers: Ground Water, v. 34, no. 6, p. 842–852.

Bair, E.S., and Lahm, T.D., 2006, Applied Problems in Groundwater Hydrology, Prentice Hall/Pearson Education, Upper Saddle River, New Jersey.

Bair, E.S., and Metheny, M.A., 2002, Remediation of the wells G & H Superfund Site, Woburn, Massachusetts: Ground Water, v. 40, no. 6, p. 657–668.

Gupta, N., and Bair, E.S., 1997, Variable-density flow in the midcontinent basins and arches region: Water Resources Research, v. 33, no. 8, p. 1785–1802.

Lahm, T.D., and Bair, E.S., 2000, Regional depressurization and its impact on the sustainability of freshwater resources in an extensive midcontinent variable-density aquifer: Water Resources Research, v. 36, no. 11, p. 3167–3177.

Lahm, T.D., Bair, E.S., and Schwartz, F.W., 1995, Use of stochastic simulation and geophysical logs to characterize spatial heterogeneity in hydrogeologic parameters: Mathematical Geology, v. 27, no. 2, p. 259–278.

Lahm, T.D., Bair, E.S., and VanderKwaak, J., 1998, Role of salinity-derived variable-density flow in the displacement of brine from a shallow, regionally extensive aquifer: Water Resources Research, v. 34, no. 6, p. 1469–1480.

Metheny, M.A., and Bair, E.S., 2001, The science behind *A Civil Action*—The hydrogeology of the Aberjona River, Wetland and Woburn wells G and H, *in* West, D.P. and Bailey, R.H., eds., Guidebook for the Geological Field Trips in New England, 2001 Annual Meeting of the Geological Society of America, p. D1–D25, Boston, Massachusetts.

Sheets, R.A., Bair, E.S., and Rowe, G.L., 1998, Use of $^3H/^3He$ ages to evaluate and improve groundwater flow models in a complex buried-valley aquifer: Water Resources Research, v. 34, no. 5, p. 1077–1089.

Springer, A.E., Bair, E.S., and Beak, D., 1996, Surface-applied tracer test at the Ohio Management Systems Evaluation Area: Environmental & Engineering Geosciences, v. 2, no. 4, p. 453–464.

Richard Clapp, DSc

Education

1967	BA, Biology, Dartmouth College, Hanover, New Hampshire
1974	MPH, Health Services, Harvard School of Public Health, Boston, Massachusetts
1989	DSc, Epidemiology, Boston University School of Public Health

Work Experience

2007–present	Adjunct Professor, University of Massachusetts, Lowell School of Health and Environment
2002–present	Professor of Public Health, Boston University School of Public Health
1995–2002	Associate Professor of Public Health, Boston University School of Public Health
1992–1995	Assistant Professor of Public Health, Boston University School of Public Health
1989–1994	Director, Center for Environmental Health Studies, John Snow, Inc., Boston, Massachusetts
1980–1989	Director, Massachusetts Cancer Registry, Massachusetts Department of Public Health, Boston, Massachusetts

Other Experience

Dr. Clapp has been deeply involved in community-based environmental health studies, including the Woburn, Massachusetts childhood leukemia investigations, while he directed the Massachusetts Cancer Registry, and the Tom's River, New Jersey childhood cancer study as a consultant employed at the JSI Center for Environmental Health Studies. He has also provided technical assistance to community and labor organizations and has served since 2006 as a member of the Community Assistance Panel for the ATSDR Camp Lejeune health studies. He is an Associate Editor of Environmental Health Perspectives and on the Editorial Board of New Solutions, a journal of occupational and environmental health policy.

Professional Societies

- American Public Health Association
- Massachusetts Public Health Association
- Society for Epidemiologic Research
- International Society for Environmental Epidemiology
- Massachusetts Coalition for Occupational Safety and Health

Honors and Awards

- Research Integrity Award, International Society for Environmental Epidemiology (2008)
- Science for the Benefit of Environmental Health, Boston University Superfund Basic Research Program (2006)
- Member, Harvard School of Public Health Occupational Health Program Advisory Committee (2000–2008)
- Vice-Chair, Greater Boston Physicians for Social Responsibility Steering Committee (1999–2008)
- Chair, Massachusetts Toxics Use Reduction Institute Science Advisory Board (1994–1996); Member (1994–2003)
- Marla Frazin Award, Massachusetts Breast Cancer Coalition (2002)
- Public Scientist of the Year Award, Association for Science in the Public Interest (2001)

Memberships and Registrations

- American College of Epidemiology (1989–2009)

Selected Publications

Clapp, R., 2002, Popular epidemiology in three contaminated communities: Annals of the American Academy Political and Social Science, v. 584, p. 35–46.

Clapp, R., 2006, Mortality among US employees of a large computer manufacturing company: 1969–2001: Environmental Health: A Global Access Science Source, v. 5, no. 30.

Clapp, R., and Ozonoff, D., 2004, Environment and health: Vital intersection or contested territory: American Journal of Law & Medicine, v. 30, p. 189–215.

Clapp, R., Hoppin, P., and Kriebel, D., 2006, Erosion of the integrity of public health science in the USA: Occupational and Environmental Medicine, v. 63, p. 367–368.

Clapp, R., Howe, G., and Jacobs, M., 2006, Environmental and occupational causes of cancer revisited: Journal of Public Health Policy, v. 27, p. 61–76.

Clapp, R., Jacobs, M., and Loechler, E., 2008, Environmental and occupational causes of cancer: New evidence 2005–2007: Review of Environmental Health, v. 23, p. 1–37.

Clapp, R., Proctor, S.P., and MacMillan, A., 2002, Cancer incidence in Massachusetts Persian Gulf War veterans: Epidemiology, v. 13, p. S213.

Clapp, R.W., and Hoffman, K., 2008, Cancer mortality in IBM Endicott plant workers, 1969–2001: An update on a New York production plant: Environmental Health, v. 7, no. 13.

Silver, K., and Clapp, R., 2006, Environmental surveillance at Los Alamos: An independent assessment of historical data: Risk Analysis, v. 26, no. 4, p. 893–906.

Robert M. Clark, PhD, PE, DEE

Education

1960 BS, Civil Engineering and Mathematics, Oregon State University
1961 BS, Mathematics, Portland State University, Oregon
1964 MS, Mathematics, Xavier University, Cincinnati, Ohio
1968 MS, Civil Engineering, Cornell University, New York
1976 PhD, Environmental Engineering, University of Cincinnati, Ohio

Work Experience

Dr. Clark is a registered engineer and worked as an environmental engineer at the U.S. Public Health Service and the U.S. Environmental Protection Agency (USEPA) since 1961. He was Director of the USEPA Water Supply and Water Resources Division (WSWRD) from 1985–1999. In 1999, he was appointed to a senior expert position at the USEPA. After September 2001, Dr. Clark was appointed senior scientist to the USEPA Water Protection Task Force, where he served until he retired in August 2002. He has made major contributions to the field of public health and has been professionally active at the national and international level. He has served as a member of a number of internationally recognized organizations and held national level offices for the American Society of Civil Engineers (ASCE) and the American Water Works Association (AWWA). Dr. Clark is an active researcher, having authored or coauthored more than 375 papers and publications and five books; he is now an independent consultant.

Current Work

Dr. Clark has worked extensively on issues related to homeland security including the development of early warning system for drinking-water utilities. He has been responsible for calibrating water-quality models for use in drinking water-distribution systems and for research on the effects of hydrodynamics on the transport and deposition of contaminants in networks. In addition to his work in homeland security, he has worked with the U.S. Department of State to develop criteria for drinking-water treatment in U.S. embassies. He is an Adjunct Professor of Civil and Environmental Engineering at the University of Cincinnati and recently completed service as a member of the National Research Council's Committee on "Public Water Distribution Systems: Assessing and Reducing Risks." Dr. Clark is a member of the Water District Study Group appointed by the City of Cincinnati to study the feasibility of creating a Regional Water Utility from what is currently the Greater Cincinnati Water Works. He is a member of the research team established under the USEPA's Water Research Adaptation Program (WRAP). The WRAP program (being conducted by the University of Cincinnati) is conducting research on strategies and programs that will allow water and waste water utilities to effectively adapt to global climate change. Dr. Clark has recently conducted a research study funded by the USEPA and carried out by Eastern Research Group, Inc., to develop a condition assessment model for predicting repair, replacement, and rehabilitation of drinking water distribution system infrastructure components.

Professional Societies and Honors

Dr. Clark is a national and international expert in the field of environmental engineering. He has received numerous awards including:

- Environmental and Water Resources Institute's (American Society of Civil Engineers) Best Paper Award from the Journal of Water Resources Planning and Management for 2006.
- ASCE, Lifetime Achievement Award (2004). Environmental and Water Resources Institute. In recognition of a life-long and eminent contribution to the environmental and water resources engineering disciplines through practice, research and public service.

- USEPA, Distinguished Service Career Achievement Award (2002). For leadership both as a researcher and manger in protecting the nation's public health through his research in drinking water.
- USEPA, Diversity Leadership Award (1998). Office of Research and Development. For enhancing the careers of ORD staff.
- ASCE, Rudolph Hering Medal (1996). For the best paper published by the Environmental Engineering Division.
- USEPA, Gold Medal (1993). For work during the 1993 *Cryptosporidia* outbreak in Milwaukee, Wisconsin.
- AWWA, A.P. Black Award (1993). For outstanding achievements in water-supply research.
- AWWA Publication Award (1990).
- ASCE, Outstanding Research Paper (1987). From Water Resources Planning and Management Division.
- U.S. Public Health Service Meritorious Service Award (1983).
- Walter L. Huber Civil Engineering Research Prize (1980).

Recent Publications

Berger, P.S., Clark, R.M., Reasoner, D.J., Rice, E.W., and Santo Domingo, J.W., 2009, Drinking Water, *in* Schaechter, M., ed., Encyclopedia of Microbiology: Elsevier Science, New York, p. 121–137.

Buchberger, S.G., Clark, R.M., Grayman, W.M., Li, Z., Tong, S., and Yang, Y.J., 2008, Impacts of Global Change on Municipal Water Distribution Systems: Proceedings of 2008 International Symposium on WDSA, August 17–20, 2008, Kruger Park, South Africa.

Clark, R.M., and Haught, R.C., 2005, Characterizing pipe wall demand: Implications for water quality modeling: Journal of Water Resources Planning and Management, v. 131, no. 3, p. 208–217.

Clark, R.M., Chandrasekaran, L., and Buchberger, S., 2006, Modeling the Propagation of Waterborne Disease in Water Distribution Systems: Results from a Case Study, 8th Annual Water Distribution Systems Analysis Symposium, August 27–30, 2006, Cincinnati, Ohio.

Clark, R.M., Sivaganesan, M., Rice, E.W., and Chen, J., 2002, Development of a Ct equation for the inactivation of *cryptosporidium* oocysts with chlorine dioxide: Water Research, v. 36, p. 3141–3149.

Gitas, V., Haught, R., Clark, R.M., and Rothenberg, G., 2002, Assessing the removal of inorganic colloids and *cryptosporidium* parvum from drinking water: Journal of Environmental Monitoring, v. 4, p. 1–7.

Panguluri, S., Grayman, W.M., and Clark, R.M., 2005, Water Distribution System Analysis: Field Studies, Modeling, and Management; A Reference Guide for Utilities, U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, EPA/600/R-06/028.

Panguluri, S., Grayman, W.M., Clark, R.M., Krishnan, E. Radha, G., Lucille, M., Patterson, Craig L., and Haught, R.C., 2008, Water Quality in Small Community Distribution Systems-A Reference Guide for Operators, U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, EPA/600/R-08/039.

Yang, Y J., Goodrich, J.A , Clark, R.M., and Li, S.Y., 2008, Modeling and testing of reactive contaminant transport in drinking water pipes: Chlorine response and implications for online contaminant detection: Water Research, v. 42, p. 1397–1412.

David E. Dougherty, PhD

Education

1975	BS, Engineering, Swarthmore College
1976	MSCE, Civil Engineering, Tufts University
1983	MA, Civil Engineering, Princeton University
1985	PhD, Civil Engineering, Princeton University, Water Resources Program

Work Experience

1994–present	Principal and Cofounder, Subterranean Research, Inc.
2001–2004 2007–2008	Research Associate Professor, Department of Civil and Environmental Engineering, University of Vermont
1994–2001	Associate Professor, Department of Civil and Environmental Engineering (secondary appointment in Computer Science), University of Vermont
1990–1994	Assistant Professor, Department of Civil and Environmental Engineering, University of Vermont
1991–1994	Engineer and Participating Guest, Lawrence Livermore National Laboratory
1986–1990	Assistant Professor, Department of Civil and Environmental Engineering, University of California, Irvine
1981–1982	Engineer, GeoTrans, Dames & Moore
1976–1979	Engineer, Moretrench American and Ground/Water Technology

Selected Professional Activities

Committee Participation

- American Society of Civil Engineers (ASCE) Long Term Monitoring Optimization Task Committee (2000–2006, Chair 2004–2006)
- American Geophysical Union (AGU) Groundwater Technical Committee (1994–2006, Chair during 1998–2000)
- ASCE Task Committee on Computational Issues for Groundwater Remediation Optimization (1994–1996)
- High Performance Computing Research Centers External Advisory Committee, Los Alamos National Laboratory and Oak Ridge National Laboratory (1992–1997)
- ASCE Groundwater Committee, Water Resources Planning and Management Section (2003–present)
- Vermont–EPSCoR, Management Committee (1996–1999)

Panel Member

- Expert Peer Review Panel Evaluating ATSDR's Water Modeling Activities in Support of the Current Study of Childhood Birth Defects and Cancer at U.S. Marine Corps Base Camp Lejeune, North Carolina, ATSDR (2005)
- Hydraulic Optimization Demonstration Project, U.S. Environmental Protection Agency (USEPA) Technology Innovation Office (1998–1999)
- Environmental Management Science Program, U.S. Department of Energy (1999)
- Hazardous Waste Research Centers Program, USEPA (1998)
- Strategic Environmental Research and Development Program, U.S. Department of Defense (1998)

Selected Publications

Cohen, H.A., Tonkin, M.J., Wilson, D.A., and Dougherty, D.E., 2007, A systematic data-driven approach to evaluating hydraulic capture at Superfund sites in USEPA Region 5, Geological Society of America Annual Meeting, paper 2–12.

Dougherty, D.E., and Marryott, R.A., 1991, Optimal groundwater management: 1. Simulated annealing: Water Resources Research, v. 27, no. 10, p. 2493–2508.

Dougherty, D.E., and others, 2002, Optimization and modeling for remediation and monitoring, Chapter 3, *in* Chien, C.C., and others, eds., Environmental Modeling and Management: Theory, Practice, and Future Directions: Today Media, Inc.

Dougherty, D.E., and Wilson, D.A., 2003, Using on-going monitoring data and site models to evaluate performance of remediation systems: Proceedings MODFLOW and More 2003: Understanding through modeling: Golden, Colorado, International Ground Water Modeling Center.

Dougherty, D.E., and Young, S., 2003, Hydrologic data assimilation applied to groundwater plume monitoring planning: Proceedings MODFLOW and More 2003: Understanding through modeling: Golden, Colorado, International Ground Water Modeling Center.

Eppstein, M.J., and Dougherty, D.E., 1996, Simultaneous estimation of transmissivity values and zonation: Water Resources Research, v. 32, no. 11, p. 3321–3336.

Eppstein, M.J., Dougherty, D.E., Troy, T.L., and Sevick-Muraca, E.M., 1999, Biomedical optical tomography using dynamic parameterization and Bayesian conditioning on photon migration measurements: Applied Optics, v. 38, p. 2138–2150.

Kosegi, J.M., Minsker, B.S., and Dougherty, D.E., 2000, A feasibility study of thermal in situ bioremediation of dense nonaqueous phase liquids: Journal of Environmental Engineering, v. 126, no. 7, p. 601.

Rizzo, D.M., and Dougherty, D.M., 1994, Characterization of aquifer properties using artificial neural networks, Neural kriging: Water Resources Research, v. 30, no. 20, p. 483–497.

Rizzo, D.M., and Dougherty, D.M., 1996, Design optimization for multiple management period groundwater remediation: Water Resources Research, v. 32, no. 8, p. 2549–2561.

Rizzo, D.M., and Dougherty, D.M., 2000, Artificial neural networks in subsurface characterization, *in* Govindaraju, R.S., and Rao, A.R., eds., Artificial Neural Networks in Hydrology: Kluwer.

Rizzo, D.M., Dougherty, D.M., and Yu, M., 2000, An Adaptive Long-Term Monitoring and Operations System (aLTMOs™) for optimization in environmental management: ASCE 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management, Minneapolis.

Task Committee on the State of the Art in Long-Term Groundwater Monitoring Design of the Environmental and Water Resources Institute, 2003, Long-Term Groundwater Monitoring: The State of the Art: American Society of Civil Engineers, 103 p.

Xue, G., Lillys, T.P., and Dougherty, D.E., 2000, Computing the minimum cost pipe network interconnecting one sink and many sources: SIAM Journal on Optimization, v. 10, no. 1, p. 22.

Yu, M., and Dougherty, D.E., 2000, Modified total variation method for 3-D electrical resistance tomography inverse problems: Water Resources Research, v. 36, no. 7, p. 1653.

Rao S. Govindaraju, PhD

Education

1984	B. Tech., Indian Institute of Technology, Kharagpur, India
1986	MS, University of Kentucky
1989	PhD, University of California, Davis

Work Experience

2006–present	Christopher B. and Susan S. Burke Professor of Civil Engineering, School of Civil Engineering, Purdue University, Indiana
2001–present	Professor, School of Civil Engineering, Purdue University, Indiana
1997–2001	Associate Professor, School of Civil Engineering, Purdue University, Indiana
1996–1997	Associate Professor, Department of Civil Engineering, Kansas State University
1993–1996	Assistant Professor, Department of Civil Engineering, Kansas State University
1989–1992	Research Associate (non-tenure track), University of California, Davis

Other Experience

- Editor, Surface Water Section, American Society of Civil Engineers (ASCE) Journal of Hydrologic Engineering (2004–present)
- Associate Editor, ASCE Journal of Irrigation and Drainage Engineering (1994–1998)
- Associate Editor, ASCE Journal of Hydrologic Engineering (1996–2004)

Memberships in Professional and Scholarly Societies

- Member of American Geophysical Union (1987–present)
- Member of ASCE (1993–present)
- Member of European Geophysical Society (1996–present)
- Life member of Indian Association of Hydrologists (1997–present)
- Surface Water Hydrology Committee, ASCE (1994–present)
- Publications Committee, ASCE Journal of Irrigation and Drainage Engineering (1993–1998)
- Publications Committee, ASCE Journal of Hydrologic Engineering (1996–present)
- Ground Water Hydrology Committee, ASCE Water Resources Engineering Division (1994–present)

Honors and Awards

- Arid Lands Hydraulic Engineering Award (2009), ASCE
- Walter L. Huber Civil Engineering Research Prize (2004), ASCE
- Best paper award (2003), ASCE Journal of Hydrologic Engineering
- Best Reviewer Award (1993) for ASCE Journal of Irrigation and Drainage Engineering
- Numerous invited and keynotes lectures
- Twice awarded the Regents Fellowship at University of California, Davis (campus-wide award based on merit)
- Recipient of fellowship at University of Kentucky (merit based)
- Winner of J.C. Ghosh Memorial Scholarship for academic merit at Indian Institute of Technology (IIT), Kharagpur, India
- Winner of silver medal for first position at IIT, Kharagpur, India

Chairmanship in National Committees

- Task Committee on "Artificial Neural Networks in Hydrology" sponsored by the Surface Water Committee of ASCE (1997–2000)
- Task Committee on "Stochastic Methods in Subsurface Contaminant Transport" sponsored by the Groundwater Committee of ASCE (1997–2000)
- Task Committee on "Role of Runon Effect on Surface and Subsurface Hydrologic Processes" sponsored by the Surface Water Committee of ASCE (2005–2008)
- Surface Water Hydrology Committee, ASCE (Currently vice-chair; Chair from October 2006)
- Chairman, Surface Water Task Committee, ASCE

Selected Publications

Dr. Govindaraju has been an author/co-author of over 90 refereed journal papers, a dozen book chapters, and numerous conference papers and reports. His book authorships are presented below.

Banks, M.K., Govindaraju, R.S., Schwab, A.P., Kukalow, P., and Finn, J., 2000, Phytoremediation of Hydrocarbon-Contaminated Soils, CRC Press, New York.

Govindaraju, R.S., 2002, Stochastic Methods in Subsurface Contaminant Hydrology, ASCE Press, New York (edited book).

Govindaraju, R.S., and Das, B.S., 2007, Moment Analysis for Hydrologic Applications, Kluwer Academic Publishers, Amsterdam (in press).

Govindaraju, R.S., and Rao, A.R., 2000, Artificial Neural Networks in Hydrology, Kluwer Academic Publishers, Amsterdam (edited book).

Walter M. Grayman, PhD, PE, DWRE

Education

1967	BS, Civil Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania
1969	MS, Civil Engineering, Massachusetts Institute of Technology
1971	PhD, Civil Engineering, Massachusetts Institute of Technology

Work Experience

1983–present	Owner, W.M. Grayman Consulting Engineer
1974–1983	Project Manager/Executive Vice President, W.E. Gates & Associates
1972–1974	Engineer, Engineering Science, Inc.
1971–1972	Project Manager, Argentina Water Resources Study, M.I.T.

Other Experience

2005–present	Adjunct Professor, Department of Civil and Environmental Engineering, University of Cincinnati, Ohio
2007–2009	Consultant, U.S. Environmental Protection Agency (USEPA) National Homeland Security Research Center; Water distribution system modeling in the design of contaminant warning systems
2003–2005	Consultant, Agency for Toxic Substances and Disease Registry (ATSDR); Assistance in design of water distribution system field studies and model application
1995–2000	Consultant, United Nations Industrial Development Organization (UNIDO); Pollution prevention projects in Vietnam, Turkey, and Ecuador
1992–1998	Chair and member, City of Cincinnati Environmental Advisory Council
1983–1992	Consultant, USEPA Water Supply and Water Resources Division; Development and application of hydraulic/water quality models and field sampling methods for studying movement of contaminants in water distribution systems

Professional Societies

- American Society of Civil Engineers (ASCE)/Environmental & Water Resources Institute (EWRI)
- Current and past member of several ASCE & EWRI committees
- Chair, EWRI Environmental/Water Resources 2050 Vision Task Committee
- Chair, Executive Committee (EXCOM), ASCE, Water Resource Planning and Management Division
- Associate Editor, ASCE Journal Water Resources Planning & Management
- American Water Works Association (AWWA)
- Member, AWWA Engineering Computer Applications Committee
- Member, AWWA Distribution Research Committee
- Chair, AWWA Computer Advances Committee
- International Water Association (IWA)
- American Geophysical Union (AGU)
- American Water Resources Association (AWRA)

Honors and Awards

- AWWA Engineering & Construction Division Best Paper Award (2005)
- ASCE/EWRI Service to the Profession Award (2004)
- ASCE Rudolph Hering Medal (1996)
- AWWA Engineering & Construction Division Best Paper Award (1995)

Memberships and Registrations

- Registered Professional Engineer, State of Ohio, 1977
- Diplomate, American Academy of Water Resources Engineers

Selected Publications

Clark, R.M., and Grayman, W.M., 1998, Modeling Water Quality in Drinking Water Systems, AWWA.

Grayman, W.M., 2006, A Quarter of a Century of Water Quality Modeling in Distribution Systems: Proceedings, Water Distribution System Symposium, University of Cincinnati, Ohio.

Grayman, W.M., 2006, Use of Distribution System Water Quality Models in Support of Water Security, *in* Pollert, J., and Dedus, B., eds., Security of Water Supply Systems: From Source to Tap, Springer Press, Netherlands.

Grayman, W.M., and Kirmeyer, G., 1999, Water Quality of Storage, in Mays, L.W., ed., Water Distribution System Handbook, McGraw-Hill, New York.

Grayman, W.M., Buchberger, S., and Samuels, W., 2008, Hydraulic Models of Buildings for Use in Contamination Studies: Proceedings, Water Distribution System Analysis Conference, South Africa.

Grayman, W.M., Clark, R., Grablutz, F., Sivagananesan, M., and Schade, T., 2001, Modeling the Impacts of Fire Flows on Distribution System Water Quality, Design, and Operation: Proceedings EWRI World Water & Environmental Resources Congress, ASCE, Reston, Virginia.

Grayman, W.M., Clark, R.M., Harding, B.L., Maslia, M., and Aramini, J., 2004, Reconstructing Historical Contamination Events, in Mays, L.W., ed., Water Security and Safety Handbook, McGraw-Hill, New York.

Grayman, W.M., Deininger, R.A., Males, R.M., and Gullick, R.W., 2004, Source Water Early Warning Systems, in Mays, L.W., ed., Water Security and Safety Handbook, McGraw-Hill, New York.

Grayman, W.M., Murray, R., and Savic, D.A., 2009, Effects of Redesign of Water Systems for Security and Water Quality Factors: Proceedings EWRI-ASCE World Water & Environmental Resources Congress.

Grayman, W.M., Rossman, L., and Geldreich, E., 1999, Water Quality, in Mays, L.W., ed., Water Distribution System Handbook, McGraw-Hill, New York.

Grayman, W.M., Rossman, L.A., Deininger, R.A., Smith, C.D., Arnold, C.N., and Smith, J.F., 2004, Mixing and aging of water in distribution system storage facilities: Journal of the American Water Works Association, v. 96, no. 9, p. 70–80.

Grayman, W.M., Uber, J.G., and Speight, V., 2007, Use of Distribution System Modeling in Designing Microbial Monitoring Programs: Proceedings EWRI-ASCE World Water & Environmental Resources Congress.

Panguluri, S., Grayman, W.M., and Clark, R.M., 2006, Water Distribution System Analysis: Field Studies, Modeling and Management—A Reference Guide for Utilities, USEPA, Cincinnati, Ohio.

Panguluri, S., Grayman, W.M., and Clark, R.M., 2008, Water Quality in Small Community Distribution Systems: A Reference Guide for Operators, USEPA, Cincinnati, Ohio.

Riley, M.S., Grayman, W.M., and Volock, K., 2006, How Emergency Interconnection Studies Can Improve Reliability of Service for Water Utilities: Proceedings, Water Distribution System Symposium, University of Cincinnati, Ohio.

Walski, T.M., Chase, D.V., Savic, D.A., Grayman, W., Beckwith, S., and Koelle, E., 2003, Advanced Water Distribution Modeling and Management, Haestad Methods, Haestad Press, Waterbury, Connecticut.

Benjamin L. Harding, PE

Education

1971 BS, Civil Engineering, University of Colorado

Memberships and Registrations

- Registered Professional Engineer, State of Colorado, 1979
- Member, American Society of Civil Engineers
- University of Colorado, Department of Civil, Environmental and Architectural Engineering, Professional Advisory Board Member, 1995–2003; Chair, 2000–2002

Work Experience

Mr. Harding has more than 35 years of diverse experience in water-resources engineering.

For more than 20 years he has focused his practice on the design, development, and use of hydrologic and river/reservoir system models, decision support systems, hydraulic models, water-quality models, GIS, and databases. This experience includes over 20 years of project management, successfully directing engineers, scientists, and programmers in these areas.

Mr. Harding is fluent or has a working knowledge of several computer languages and has experience with the management of software and database development projects.

Mr. Harding's work has been reported in papers published in Water Resources Research, Water Resources Bulletin and Industrial Wastes.

Project Experience

- **Colorado River Water Availability.** Project manager and lead engineer for development of probabilistic estimates of water availability on the Colorado River under different assumptions regarding operating rules and legal interpretations of compacts.
- **Water Acquisition Study.** Project manager and lead engineer for evaluation of water acquisition as a means of maintaining habitat for endangered fish in a water-short river system. This analysis involves both engineering and institutional factors.
- **Central Oahu Water-Distribution System.** In support of litigation, project manager and chief engineer for analysis of the fate and transport of pesticides in the water-distribution system of Honolulu, Hawaii. Performed and directed water-distribution fate and transport modeling. Developed and utilized Monte Carlo risk-assessment methods to quantify human intakes of pesticides and associated risk of cancer. Directed the development of GIS databases used for analysis of water demand, development of water-distribution models, and geocoding of exposure locations. Provided expert testimony in deposition and at trial in Federal court. Trial is ongoing.
- **Snowmaking Water Quality Studies.** Project engineer for design of a field sampling program for hydrology and water quality of meltwater from artificial snow, and associated model studies.

- **Redlands Toxic Chemical Exposure Analysis.** In support of litigation, project manager and chief engineer for analysis of the fate and transport of toxic chemicals in the water-distribution system of Redlands, California. Performed and directed water-distribution fate and transport modeling to reconstruct historical conditions at different spatial and temporal scales. Developed and utilized Monte Carlo risk assessment methods to quantify human intakes of contaminants and associated risk of cancer. Provided expert testimony at deposition. Case is ongoing.
- **Burbank TCE Exposure Analysis.** In support of litigation, project manager and chief engineer for analysis of the fate and transport of TCE in the water-distribution system of Burbank, California. Performed and directed water-distribution fate and transport modeling to reconstruct historical conditions at different spatial and temporal scales. Provided expert testimony at deposition. Case was settled.
- **Phoenix TCE Exposure Analysis.** In support of litigation, project manager and chief engineer for analysis of the fate and transport of TCE in the water-distribution systems of Scottsdale and Phoenix, Arizona. More than 10 hydraulic and water-quality models of both systems were constructed and calibrated. These models were run over a study period spanning 20 years or more. Mr. Harding managed and conducted the development of a comprehensive historical spatial database of parcel and land use data, beginning with current land use data and developing historical data from aerial photographs and other sources. These databases were used to estimate historical water use, to develop water-distribution models, and to geocode exposure locations. Provided expert testimony at deposition and at trial in state court. Case resolved at trial.

Selected Publications

Grayman W., Clark R.M., Harding B.L., Maslia, M., and Aramini, J., 2004, Reconstructing Historical Contamination Events, *in* Mays, L., ed., Water Supply Systems Security: McGraw-Hill.

Harding, B.L., 1999, Evaluation of Historical Concentrations of Dissolved Contaminants in the Burbank Water Distribution System: February 15, 1999.

Harding, B.L., 1999, Evaluation of Historical Concentrations of Dissolved Contaminants in the Burbank Water Distribution System: Supplemental Report, May 7, 1999.

Harding, B.L., and Grayman, W., 2002, Historical Reconstruction of Contamination in a Distribution System Incorporating Uncertainty: Proceedings of the 12th Conference of the International Society of Exposure Analysis (ISEA) and 14th Conference of the International Society for Environmental Epidemiology (ISEE), August, 2002, Vancouver, British Columbia, Canada.

Harding, B.L., and Grayman, W., 2003, Movement of Contaminants in the Central Oahu Distribution System.

Harding, B.L., and Walski, T.M., 1999, Long Time-Series Simulation of Water Quality in Distribution Systems: Proceedings of the 26th Annual Water Resources Planning and Management Conference, ASCE.

Harding, B.L., and Walski, T.M., 2000, Long Time-Series Simulation of Water Quality in Distribution Systems: ASCE, Journal of Water Resources Planning and Management, v. 126, no. 4.

Walski, T.M., and Harding, B.L., 1997, Historical TCE Concentrations in Drinking Water in the Maryvale Area of West Central Phoenix, Arizona: Lofgren, et al., versus Motorola, et al., Superior Court, Maricopa County, Arizona, July 31, 1997.

Walski, T.M., and Harding, B.L., 1997, Historical TCE Concentrations in Drinking Water in South Scottsdale and Adjacent Areas of Phoenix, Arizona: Lofgren, et al., versus Motorola, et al., Superior Court, Maricopa County, Arizona, January 13, 1997.

Mary C. Hill, PhD

Education

1976	BA, Geology and Business Administration (double major), Hope College, Holland, Michigan
1976–1977	Master's Candidate, Civil Engineering—Water Resources, Michigan State University
1978	MSE, Civil Engineering—Water Resources, Princeton University, Princeton, New Jersey
1985	PhD, Civil Engineering—Water Resources, Princeton University, Princeton, New Jersey

Work Experience

2001–present	Project Chief, Research Project "Modeling and Uncertainty of Complex Ground-water Systems," National Research Program, U.S. Geological Survey, Boulder, Colorado
2007–present	Research Advisor, National Research Program, Ground-Water Hydrology Discipline, U.S. Geological Survey, Boulder, Colorado
1987–2001	Research Hydrologist, National Research Program, U.S. Geological Survey, Lakewood and then Boulder, Colorado
1981–1987	New Jersey District, Water Resources Division, U.S. Geological Survey. Projects included work in glacial and coastal environments with stream-aquifer interactions, and on Monte Carlo analysis of nonlinear confidence intervals.
1976–1981	Teaching Assistant or Research Assistant, Princeton University, Princeton, New Jersey

Other Experience

- Development of text book and curriculum to teach methods for integrating data and models
- Development of new statistics that address problems common in environmental management
- Development of software to support the pedagogical approach and the new statistics, including programs OPR-PPR and MMA, and UCODE_2005, a universal inverse modeling code
- Promotion of scientific meetings and short courses in third world countries

Professional Societies

- American Geophysical Union
- Geological Society of America
- American Society of Civil Engineers
- National Ground Water Association
- International Association of Hydrological Sciences (IAHS)
  - President of the International Commission for Groundwater of IAHS, 2005–2009

Awards

- Promotion to GS-ST, the highest level achievable by US government scientists, 2007
- National Ground Water Association M. King Hubbert Award, 2005
- Fellow of the Geological Society of America, 2003
- National Ground Water Association Distinguished Darcy Lecturer, 2001 (45 talks in 8 countries)
- American Society of Civil Engineers Walter L. Huber Engineering Research Prize, 2000

Selected Publications

Barth, G.R., and Hill, M.C., 2005, Parameter and observation importance in modeling virus transport in saturated systems–Investigations in a homogenous system: Journal of Contaminant Hydrology, v. 80, p. 107–129.

D'Agnese, F.A., Faunt, C.C., Hill, M.C., and Turner, A.K., 1999, Death Valley regional ground-water flow model calibration using optimal parameter estimation methods and geoscientific information systems: Special Section on Model Calibration and Reliability Evaluation for Ground-Water Systems, eds. A. Leijnse and M.C. Hill, Advances in Water Resources, v. 22, no. 8, p. 777–790.

Foglia, L., Hill, M.C., Mehl, S.W., and Burlando, P., 2009, Sensitivity analysis, calibration, and testing of a distributed hydrological model using error-based weighting and one objective function: Water Resources Research, v. 45, W06427, DOI:10.1029/2008WR007255.

Foglia, L., Mehl, S.W., Hill, M.C., Perona, P., and Burlando, P., 2007, Testing alternative ground water models using cross validation and other methods: Ground Water, v. 45, no. 5, p. 627–641.

Hill, M.C., and Tiedeman, C.R., 2007, Effective groundwater model calibration, with analysis of sensitivities, predictions, and uncertainty: New York, New York, Wiley, 455 p.

Hill, M.C., Cooley, R.L., and Pollock, D.W., 1998, A controlled experiment in ground-water flow model calibration: Ground Water, v. 36, no. 3, p. 520–535.

Poeter, E.P., and Hill, M.C., 1997, Inverse modeling, A necessary next step in ground-water modeling: Ground Water, v. 35, no. 2, p. 250–260.

Poeter, E.P., and Hill, M.C., 2007, MMA, a computer code for multi-model analysis: U.S. Geological Survey Techniques and Methods 6-E3. *http://igwmc.mines.edu/freeware/mma/*

Tiedeman, C.R., Ely, D.M., Hill, M.C., and O'Brien, G.M., 2004, A method for evaluating the importance of system state observations to model predictions, with application to the Death Valley regional groundwater flow system: Water Resources Research, v. 40, W12411, DOI:10.1029/2004WR003313.

Tonkin, M., Tiedeman, C.R., Ely, D.M., and Hill, M.C., 2007, OPR-PPR, a computer program for assessing data importance to model predictions using linear statistics: U.S. Geological Survey Techniques and Methods 6-E2. *http://water.usgs.gov/software/OPR-PPR/*

Leonard F. Konikow, PhD

Education

1966	BA, Geology, Hofstra University, Hempstead, New York
1969	MS, Geology, Pennsylvania State University
1973	PhD, Geology, Pennsylvania State University

Registration

- Professional Geologist, Pennsylvania (1996–present)

Work Experience

1980–present	Project Chief, Water Resources Division, U.S. Geological Survey, Research Project "Digital modeling of transport in saturated zone"
1978–1980	Ground Water Branch, U.S. Geological Survey, Reston, Virginia
1974–1978	Project Chief, Research Project "Solute Transport in Ground Water," U.S. Geological Survey, Central Region, Lakewood, Colorado
1972–1974	Project Chief, Subsurface Waste Investigations, U.S. Geological Survey, Lakewood, Colorado
1969–1971	Research Assistant, Pennsylvania State University

Other Experience

Instructor and lecturer at:

7/66–9/66	Geology Department, Hofstra University, Hempstead, New York
1/69–6/69	Geology Department, Pennsylvania State University
1991 & 1992	Department of Environmental Sciences, University of Virginia
1997	Department of Geological Sciences, Stanford University

Professional Societies

- American Geophysical Union (AGU) (1970–present; elected Fellow, 2001)
- AGU Spring Meeting Program Chairman for Hydrology (1984–1987)
- Groundwater Committee (1977–1986; Chairman, 1980–1982)
- Geological Society of America (1974–present; Fellow since 1990)
- Management Board, Hydrogeology Division, Geological Society of America (GSA) (1991–1995)
- Chairman, Hydrogeology Division, GSA (1993–1994)
- International Association of Hydrogeologists (IAH) (1985–present); IAH Vice President, North America and IAH Executive Council (2009-2012)
- Chairman of U.S. National Chapter, IAH (2001–2004)
- Association of Ground Water Scientists and Engineers (AGWSE) (Technical Division of National Ground Water Association) (1990–present)
- AGWSE—Board of Directors (1996–2000)
- American Institute of Hydrology (Certified as Professional Hydrogeologist) (1991–present)
- California Groundwater Resources Association (2002–present)

Honors and Awards

- Birdsall Distinguished Lecturer (1985–1986), GSA, Hydrogeology Division
- M. King Hubbert Science Award (1989), National Ground Water Association
- O.E. Meinzer Award (1997), GSA, Hydrogeology Division
- C.V. Theis Award (1998), American Institute of Hydrology
- Distinguished Service Award (1999), U.S. Department of Interior
- Award for Distinguished Service (2000), GSA, Hydrogeology Division
- Elected as Fellow (2001), AGU
- President's Award (2001), IAH
- Ineson Distinguished Lecturer, IAH British Chapter, London, UK (2005)

Selected Professional Activities

- Rocky Mountain Arsenal (Colorado) Technical Review Committee (1975–1977)
- Associate Editor, Water Resources Research (1981–1984)
- National Research Council, Panel on Groundwater Contamination (1981–1982)
- National Research Council, Water Science & Technology Board, Committee on Ground-Water Modeling Assessment (1987–1989)
- National Research Council, Waste Isolation Plot Plant Committee (1989–1997)
- Peer Review Panel, U.S. Environmental Protection Agency Environmental Monitoring Systems Lab, Las Vegas, Nevada (1991)
- National Science Foundation, Review Panel for Hydrologic Sciences and Interim Staff Assistant (1992)
- Member of Modeling Project Subcommittee, Science Advisory Board, U.S. Environmental Protection Agency (1993)
- Editorial Board, Ground Water Journal (1993–1995)
- Adviser to U.S. AID project studying seawater intrusion in Gaza and Morocco (1994–1997)
- National Research Council, Hydrogeology/Water Management Peer Review Panel for U.S. AID (2000)
- National Research Council, Committee on Principles and Operational Strategies for Staged Repository Systems (2001–2002)
- Farvolden Distinguished Lecturer, University of Waterloo (2002)
- Expert Peer Review Panel for ATSDR to evaluate historical ground-water contamination and water-supply distribution problems at Tarawa Terrace, U.S. Marine Corps Base, Camp Lejeune, NC (March 2005)
- Expert Peer Review Panel for the South Florida Water Management District (SFWMD) to evaluate East Central Florida Transient model (October 2006–February 2007)
- Coastal Sound Science Initiative Technical Advisory Committee for Georgia and South Carolina (January 2008–June 2008)

Publications

Author or coauthor of numerous articles in peer-reviewed journals, government publications, conference proceedings, book chapters, and talks given at professional society meetings (detailed list available on request).

Peter Pommerenk, PhD, PE

Education

1989 MS, Aerospace Engineering, Universität der Bundeswehr München, Germany
1996 MS, Environmental Engineering, Old Dominion University, Norfolk, Virginia
2001 PhD, Environmental Engineering, Old Dominion University, Norfolk, Virginia

Memberships and Registrations

- Member, American Water Works Association
- Registered Professional Engineer, Virginia, North Carolina

Work Experience

2002–2008 Specializes in water quality and treatment, including process design studies (bench, pilot, and full-scale plant studies), optimization of new and existing raw water supply, treatment and water-distribution system facilities for compliance purposes, impact assessment of pollutant discharges on ambient water quality, and computer-aided modeling of physiochemical processes and transport in aqueous systems. As a project manager with AH Environmental Consultants, his projects included:

Distribution System Hydraulic and Water Quality Modeling for City of Goldsboro, North Carolina; Fort Eustis, Virginia; Fort Story, Virginia; and Naval Service Warfare Center, Carderock Division, Maryland.

2002–2008 Served as project manager for completion of distribution system hydraulic and water-quality models. Tasks performed include: Development of water-quality sampling and hydraulic monitoring plans, model calibration, and development of scenarios to identify solutions to distribution system water-quality problems.

U.S. Marine Corps Base Camp Lejeune, North Carolina.

- Performed feasibility studies and preliminary design and developed cost estimates for the replacement of five water-treatment facilities with membrane nanofiltration, lime softening, and ion exchange plants.
- Designed and conducted an investigative study to determine the source of trihalomethane precursor material at a well field at the Marine Corps Air Station New River and developed well utilization schedules to minimize disinfection byproduct formation.
- Developed and conducted a study to evaluate the effect of pH adjustment and corrosion inhibitor addition on the leaching of lead from brass faucets. This work included bench-scale tests and chemical equilibrium modeling of the effects of process chemistry on the solubility of lead phosphate and carbonate minerals.
- Developed and completed study to minimize disinfection byproduct formation in the consecutive water system at the Rifle Range.
- Developed raw-water master plan for 80 groundwater wells at the base.
- Provided technical support to the base for the epidemiological study being conducted by the Agency for Toxic Substances and Disease Registry (ATSDR).
- Served on the 2005 expert panel for ATSDR's Historical Reconstruction Analysis of Camp Lejeune's water-distribution system.

U.S. Army Corps of Engineers, Washington Aqueduct Division.

Developed and conducted a full-scale study to determine the impact of backwash water recycling on granular media filtration efficiency.

City of Virginia Beach, Virginia.

As project manager developed long-term plan for alternative water supply, including conceptual design and cost estimation for seawater desalination and surface-water treatment.

U.S. Army Corps of Engineers, Washington Aqueduct Division.

Evaluated alternative filter aids for the McMillan plant in a pilot- and full-scale study to minimize the adverse impacts of algae blooms in uncovered reservoirs on filtered water-effluent turbidity and particle-size distribution.

Naval Facilities Engineering Command, Atlantic Division.

Performed sanitary surveys for overseas water-treatment facilities at the Naval Station Roosevelt Roads, Puerto Rico; the Naval Station Rota, Spain; the Naval Station Guantanamo Bay, Cuba; the Naval Support Activity Bahrain; and the Naval Support Activity Souda Bay, Greece.

Army National Guard, Camp Atterbury, Indiana.

Evaluated the influence of water-softening strategies on the leaching of lead from brass faucets. This work included bench-scale tests and chemical equilibrium modeling of the effects of process chemistry on the solubility of lead.

City of Goldsboro, North Carolina.

Responsible for providing technical support to the city on numerous projects including evaluation of alternatives to upgrade or replace the existing Neuse River Intake; safe yield analysis of the Neuse River; and evaluation of trihalomethane control alternatives, tracer studies, and computational fluid dynamics analysis of the clearwell.

Recent Publications and Presentations

Pommerenk, P., and Schafran, G.C., 2002, Effects of prefluoridation on removal of particles and organic matter: Journal of the American Water Works Association, v. 94, no. 2, p. 99–108.

Pommerenk, P., and Schafran, G.C., 2005, Adsorption of inorganic and organic ligands onto hydrous aluminum oxide: Evaluation of surface charge and the impacts on particle and NOM removal during water treatment: Environmental Science and Technology, v. 39, no. 17, p. 6429–6434.

Randall R. Ross, PhD

Education

1985 BS, Geology, Oklahoma State University, Stillwater, Oklahoma
1988 MS, Geology, Oklahoma State University, Stillwater, Oklahoma
1998 PhD, Environmental Science, University of Oklahoma

Work Experience

8/1987–present	Hydrologist, Applied Research & Technical Assistance Branch, Applied Research & Technical Support Branch, Ground Water & Ecosystems Restoration Division, National Risk Management Research Laboratory, Office of Research and Development, U.S. EPA, Ada, Oklahoma
8/1986–8/1987	Presidential Research Fellow, University Center for Water Resources Research, Oklahoma State University, Stillwater, Oklahoma
6/1985–9/1985	Hydrologist, Engineering Enterprises, Inc., Norman, Oklahoma
6/1983–9/1983	Intern, Oklahoma Water Resources Board, Surface Water Division, Oklahoma City, Oklahoma
11/1980–5/1982	Laboratory Technician, U.S. EPA, R.S. Kerr Environmental Research Laboratory, Ada, Oklahoma

Professional Memberships and Committees

- International Association of Hydrogeologists
- Oklahoma Water Resources Board Arbuckle-Simpson Aquifer Study Technical Advisory Committee
- Oklahoma Laboratory Services Advisory Committee
- National Cooperative Geologic Mapping Program Federal Advisory Committee

Selected Publications and Presentations

Bear, J., Beljin, M., and Ross, R., 1991, Fundamentals of ground-water modeling for decision makers: Ground-Water Issues, EPA/540/S-92/005.

Bear, J., Beljin, M., and Ross, R., 1994, Ground-water Modeling: Back to the Basics: Journal of Water and Environment Federation, January.

Beljin, M.S., and Ross, R.R., 1994, Application of GIS and Modeling in Remediation of Ground-water Contamination. Presented at the National Conference on Environmental Problem Solving with Geographic Information Systems, September 21–23, 1994, Cincinnati, Ohio.

Leach, L.E., and Ross, R.R., 1991, Aseptic Sampling of Unconsolidated Heaving Soils in Saturated Zones, in Nash, R.G., and Leslie, A.R., eds., Groundwater Residue Sampling Design, American Chemical Society, Washington, DC.

Ludwig, R.D., Su, C., Lee, T.R., Wilkin, R.T., Acree, S.D., Ross, R.R., and Keeley, A., 2007, In situ Chemical Reduction of Cr(VI) in Groundwater Using a Combination of Ferrous Sulfate and Sodium Dithionite: A Field Investigation: Environmental Science and Technology, v. 41, no. 15, p. 5299–5305.

Newell, C.J., and Ross, R.R., 1990, Estimating Potential for Occurrence of DNAPL at Superfund Sites. Superfund Remediation Fact Sheet, Publication 9355.4-07FS.

Newell, C.J., Acree, S.D., Ross, R.R., and Huling, S.G., 1995, Light Nonaqueous Phase Liquids: Ground-Water Issues, EPA/540/S-95/500.

Ross, R.R., 1992, Ground-water Modeling at Superfund Sites. Presented at the Ground-water Modeling Workshop, U.S. Army Corps of Engineers, June 1992, Denver, Colorado.

Ross, R.R., 1992, Limitations of Pump-and-Treat Remediation at the Gilson Road Superfund Site. Presented to the National Research Council, Subcommittee to Evaluate the Limitations of Groundwater Remediation Technologies, June 1992, Washington, DC.

Ross, R.R., 2000, State-of-the-Art Field Techniques for Site Characterization. Presented at the MTBE Scientist-to-Scientist Meeting, Argonne National Laboratory, June 20–21, 2000, Argonne, Illinois.

Ross, R.R., 2001, Monitoring and Evaluation of Containment Systems: Past, Present and Future Practices. Presented to the National Research Council, Subcommittee to Evaluate Engineered Barriers, July 2001, Washington, DC.

Ross, R.R., and Acree, S.D., 1992, Overview of DNAPL restoration in Pre-Conference Seminar Proceedings, Detection and Restoration of DNAPLs in Groundwater at Hazardous Waste Sites, 65th Annual Conference & Exposition, Water Environment Federation, Alexandria, Virginia, p. 67–73.

Ross, R.R., and Beljin, M.S., 1994, Performance Evaluation of One of the First Superfund Sites. Presented at the National Ground Water Association National Convention and Exposition, October 9–12, 1994, Las Vegas, Nevada.

Ross, R.R., and Beljin, M.S., 1995, MODRISI: A PC Approach to GIS and Ground-Water Modeling, Proceedings, National Conference on Environmental Problem-Solving with Geographic Information Systems, September 21–23, 1994, Cincinnati, Ohio, EPA/625/R-95/004.

Ross, R.R., and Beljin, M.S., 1998, Evaluation of Containment Systems Using Hydraulic Head Data: Journal of Environmental Engineering, v. 124, no. 6, p. 575–578.

Ross, R.R., and Beljin, M.S., 2000, Containment Technology and Monitoring, Abiotic In Situ Technologies for Groundwater Remediation Conference Proceedings, August 31–September 2, 1999, Dallas, Texas, EPA/625/R-99/012, p. 80–81.

Ross, R.R., Beljin, M.S., and Vieux, B.E., 2000, Application of a Geographic Information System For Containment System Leak Detection, Proceedings, National Conference on Environmental Problem-Solving with Geographic Information Systems, September 21–24, 1999, Cincinnati, Ohio, EPA/625/R-00/010.

Ross, R.R., and Vieux, B.E., 2000, A Probabilistic Method for Estimating Monitoring Point Density for Containment System Leak Detection: Ground Water, v. 38, no. 4, p. 533–540.

Schmelling, S.G., and Ross, R.R., 1989, Contaminant Transport in Fractured Media: Models for Decision Makers: Ground-Water Issues, EPA/540/4-89/004.

Schmelling, S.G., and Ross, R.R., 1990, Contaminant Transport in Fractured Media: Models for Decision Makers: Groundwater, v. 28, no. 2, p. 272–278.

Wilkin, R.T., Acree, S.D., Beak, D.G., Ross, R.R., Lee, T.R., and Paul, C.J., 2008, Field Application of a Permeable Reactive Barrier for Treatment of Arsenic in Ground Water, EPA 600/R-08/093.

Wilkin, R.T., Acree, S.D., Ross, R.R., Beak, D.G., and Lee, T.R., 2008, Performance of a Zero Valent Iron Reactive Barrier for the Treatment of Arsenic in Groundwater: Part 1. Hydrogeochemical Studies: Journal of Contaminant Hydrology, v. 106, no. 1–2, p. 1–14.

Wilkin, R.T., Acree, S.D., Ross, R.R., Lee, T.R., and Beak, D.G., 2006, An In-Situ Permeable Reactive Barrier for the Treatment of Arsenic in Ground Water. Geological Society of America Abstracts with Programs, Paper #67-6, 38(7):179, 2006 Philadelphia Annual Meeting, October 22–25, 2006.

Wilson, J.T., Ross, R.R., and Acree, S.D., 2005, Using Direct-Push Tools to Map Hydrostratigraphy and Predict MtBE Plume Diving: Ground Water Monitoring and Remediation, v. 25, no. 3, p. 93–102.

Wilson, J.T., Ross, R.R., and Acree, S.D., 2006, Using Direct-Push Tools to Map Hydrostratigraphy and Predict MTBE Plume Diving. L.U.S.T. Line, New England Interstate Water Pollution Control Commission, Bulletin 52, May 2006, p. 14–21.

Daniel Wartenberg, PhD, MPH

Education

1974	AB, cum laude (Ecology), College of Arts and Sciences, Cornell University, Ithaca, New York
1977	MS, Oceanography (Biological), University of Washington (Seattle)
1984	PhD, Ecology and Evolution, State University of New York at Stony Brook
1986	Fellow, Interdisciplinary Programs in Health, Harvard School of Public Health, Boston, Massachusetts

Work Experience

2006–present	Director, Division of Environmental Epidemiology and Statistics, Environmental and Occupational Health Sciences Institute, Piscataway, New Jersey
2004–present	Chief, Division of Environmental Epidemiology, Department of Environmental and Occupational (formerly Community) Medicine, Robert Wood Johnson Medical School, University of Medicine and Dentistry of New Jersey (UMDNJ)
2002–2005	Leader, Population Science Program (a.k.a., Cancer Control Program), Cancer Institute of New Jersey, New Brunswick, New Jersey
2001–present	Professor, Division of Epidemiology, UMDNJ School of Public Health (SPH), Piscataway/New Brunswick Campus
1999–present	Professor, Department of Environmental and Community Medicine, Robert Wood Johnson Medical School, UMDNJ
1992–1999	Associate Professor, Department of Environmental and Community Medicine, Robert Wood Johnson Medical School, UMDNJ
1990–present	Member, Doctoral Committee, UMDNJ SPH; Chair, 1997–2001
1986–1992	Assistant Professor, Department of Environmental and Community Medicine, Robert Wood Johnson Medical School, UMNDJ

Other Experience

National Research Council Committees (NAS or IOM) (of several)

- Review Coordinator for a National Research Council of the National Academies of Sciences report: Identification of Research Needs Relating to Potential Biological or Adverse Health Effects of Wireless Communications Devices (2007)
- Invited Author, Using Disease Cluster and Small-Area Analysis to Study Environmental Justice, 1997, p. 79–102, in Institute of Medicine, 1999, Toward Environmental Justice: Research, Education, and Health Policy Needs: National Academy Press, Washington, DC.
- Member, Committee on Possible Biological Effects of Electromagnetic Fields (1993–1996)

Editorial Positions

- 1991–1997 Editorial Board, New Solutions
- 1993/1995/2005 Guest Co-Editor, Statistics in Medicine Special Issue on "Disease Clusters"
- 1994–1998 Editorial Collaborator, Environmental and Ecological Statistics
- 1999–2001 Associate Editor, American Journal of Public Health
- 2009–present Associate Editor, Spatial and Spatio-temporal Epidemiology

Professional Societies

- International Society for Environmental Epidemiology (President 2006–2007)
- Society for Epidemiologic Research
- American College of Epidemiology
- International Society of Exposure Science
- International Epidemiological Association
- American Public Health Association

Honors and Awards

- Visiting Scholar, Mel and Enid Zuckerman College of Public Health, University of Arizona (2007)
- Libra Scholar, University of Southern Maine, Portland, Maine (2005)
- Best Paper Award, Society for Risk Analysis, Seattle, Washington (2001)
- Gallo Award for Outstanding Cancer Research, Cancer Institute of New Jersey (2001)
- Elected to the National Council on Radiation Protection and Measurement (2001)
- Elected Fellow of the American College of Epidemiology (2000)
- Outstanding Teacher Award, New Jersey Graduate Program in Public Health, Graduating Class of 1990 (1990)

Selected Publications

Bukowski, J.A., and Wartenberg, D., 1997, An alternative approach for investigating the carcinogenicity of indoor air pollution: Pets as sentinels of environmental cancer risk: Environmental Health Perspectives, v. 105, no. 12, p. 1312–1319.

Corrigan, M., McWilliams, M., Kelly, K.J., Niles, J., Cammarata, C., Jones, K., Wartenberg, D., Hallman, W.K., Kipen, H., Glass, L., Schorr, J.K., Feirstein, I., and Prezant, D.J., 2009, FDNY World Trade Center firefighters* mental health—Computerized self-administered questionnaire to identify symptoms, PTSD & counseling service use: American Journal of Public Health (in press).

Elliott, P., and Wartenberg, D., 2004, Spatial epidemiology: Current approaches and future challenges: Environmental Health Perspectives, v. 112, no. 9, p. 998–1006.

Laumbach, R.J., Harris, G., Kipen, H.M., Georgopoulos, P., Shade, P., Efstathiou, C., Isukapalli, S.S., Galea, S., Vlahov, D., and Wartenberg, D., 2009, Respiratory symptoms are not associated with estimated WTC plume intensity and respiratory symptoms among residents outside of lower Manhattan: American Journal of Epidemiology (in press).

Radican, L., Wartenberg, D., Rhoads, G., Schneider, D., Wedeen, R., Steward, P., and Blair, A., 2006, A retrospective occupational cohort study of end-stage renal disease in aircraft workers exposed to trichloroethylene and other hydrocarbons: Journal of Occupational and Environmental Medicine, v. 48, no. 1, p. 1–12.

Wartenberg, D., 2001, Investigating disease clusters: Why, when and how: Journal of the Royal Statistical Society, Series A, v. 164, part 1, p. 13–22.

Wartenberg, D., Reyner, D., and Scott, C.S., 2000, Trichloroethylene and cancer: The epidemiologic evidence: Environmental Health Perspectives, v. 108, supplement 2, p. 161–176.